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Recognition of facial expressions of pain using spatial frequency information

Wang, Shan

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Shan Wang

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Declaration

I declare that the work presented in this thesis is the result of my own work.

Chapter 3–4 is based on the paper by Wang, S., Eccleston, C., & Keogh, E. (2015). The role of spatial frequency information in the recognition of facial expressions of pain. *Pain*, *156*(9), 1670–1682.

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Abstract

Individuals' pain experiences can be communicated both verbally and non-verbally. Facial expressions are a primary non-verbal channel of pain communication, and so need to be clearly and unambiguously recognised and differentiated from other non-noxious emotional expressions. It is known that we are able to identify others' pain from their facial expressions in an accurate and efficient manner, even under challenging visual conditions. However, little is known about how facial expressions are processed by observers, and what information is actually used, to make the identification of pain possible. To account for this, the current thesis considered facial expressions as a type of visual stimulus and investigated possible mechanisms that underpin the recognition of pain expressions from the perspective of perceptual information analysis.

Spatial frequency (SF) information is a type of fundamental perceptual information that encodes different characteristics of a visual display. For a facial expression, low-SF information conveys the large-scale facial configuration and structural changes, whereas high-SF information depicts the fine details of facial features. In order to understand how we recognise pain expressions in terms of SF analysis, a series of experiments were conducted within this thesis to primarily investigate the *role* of low-SF and high-SF information in the recognition of pain expressions (Experiment 1–4), and the *temporal feature* of low-SF and high-SF information processing in pain recognition (Experiment 5–7).

Data of this thesis revealed that although pain expressions could be recognised with either low-SF or high-SF information available, low-SF information plays a prominent role that leads to more accurate judgements (Experiment 1) and is preferentially perceived by observers (Experiment 2–4). Moreover, the processing of low-SF information shows a temporal advantage over high-SF information (Experiment 5). Pain expressions presented with low-SF information only was decoded more rapidly than those presented with high-SF (Experiment 6), and the asynchrony between low-SF and high-SF processing

originated from a very early stage of information extraction (Experiment 7). Therefore, the decoding of low-SF pain expressions is not only faster in duration but also precedes the decoding of high-SF pain.

Altogether, these findings suggest that when we differentiate facial expressions of pain from non-noxious emotions, the coarse low-SF information plays a key role by providing a preliminary understanding of the overall quality of pain expressions rapidly, and the fine-detailed high-SF information is integrated at a later stage and plays a trivial role. More interestingly, this pattern was found not only for the recognition of pain expressions, but also the core emotions investigated, which suggests that expressions of pain and core emotions share similar visual perceptual properties.

This thesis provides a visuoperceptual account of how we recognise facial expressions of pain and suggests that in addition to analysing a series of facial action units the recognition of pain expressions is also a visual perceptual process that relies heavily on the perceptual information analysis. Limitations that were associated with the research contained within this thesis were acknowledged, suggesting directions for future research.

Chapter 1 Introduction

This chapter is a general introduction that aims to provide the background information and the context in which this PhD research is rooted and the general rationale of this thesis.

Pain is a distressing experience consisting of sensory, emotional, cognitive and social components (Williams & Craig, 2016). While pain is a highly personal and subjective experience, it happens in social contexts and requires communication to elicit others' helping behaviour and/or alert others to potential dangers in the environment. Pain can be communicated through multiple channels, not only verbally but also non-verbally. Facial expression is a primary nonverbal method of pain communication, in particular for those who are not able to use language to express their pain experiences effectively. It is important to clearly and unambiguously recognise others' facial expressions of pain, and what is more important to understand is how we process facial expressions to make the recognition of pain possible, and whether it is similar to or different from recognising other non-noxious facial expressions. This thesis, therefore, aims to discover the possible mechanisms underpinning the recognition of facial expressions of pain and compare with core emotions.

1.1 What is pain?

According to the International Association for the Study of Pain (IASP), pain is defined as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" (Merskey & Bogduk, 1994). This definition highlights the aversiveness of pain experience, the physical and psychological qualities of pain, and the connection between painful sensation and presumed harm to an organism. As the most widely used definition, it identifies the core characters of pain as a distressing subjective experience and its possible physical causes, however, two very important components are missing – the cognitive and social components of pain (Williams & Craig, 2016).

Cognitively, the threatening nature of pain functions to interrupt the ongoing cognitive activities by demanding one's attention, eliciting prolonged emotional responses, and altering behaviours to avoid or reduce pain (Crombez, Eccleston, Van Damme, Vlaeyen, & Karoly, 2012; Eccleston & Crombez, 1999; Eccleston, 2015; Vlaeyen, Crombez, & Linton, 2016). More importantly, pain happens in social environments and requires communication. Social contexts and interpersonal factors modulate individuals' pain (Craig, 2015; Krahé, Springer, Weinman, & Fotopoulou, 2013), and the aversive and distressing qualities of pain experience provoke sufferers to communicate such signals to the social environment that potentially elicit others' responses (Craig, 2009, 2015; Hadjistavropoulos et al., 2011; Hadjistavropoulos, Craig, & Fuchs-Lacelle, 2004).

While the cognitive and social mechanisms for pain have been described in many theories and models, these components have failed to be acknowledged in the definition of pain until recently. In the most recent update of the definition of pain, the cognitive and social dimensions are included, and a more comprehensive view into pain experience is provided – "pain is a distressing experience associated with actual or potential tissue damage with sensory, emotional, cognitive and social components" [1] (Williams & Craig, 2016).

In this thesis, I will use this updated definition of pain and primarily focus on one important feature of the social component – the communication of pain. The communication aspect is acknowledged in the social dimension of pain experience, including both expressing distress to others and others' experience and responses. More specifically, it has been developed to include the behaviours that express pain nonverbally (e.g. facial expressions) and recognise the importance of nonverbal communication in pain assessment, especially for individuals who are unable to communicate verbally. These features are particularly relevant to the current thesis that focuses on the non-verbal communication of pain. In the following section, I

[1] It should be noted that this updated definition of pain has not yet been officially adopted by IASP.

will provide an overview of the communication aspect of pain, by summarising the methods and the models of pain communication.

1.2 How do we communicate pain?

Pain is a personal and subjective feeling, which cannot be measured directly but only inferred from overt evidence (Craig, 2005; Fordyce, Fowler, Lehmann, & DeLateur, 1968; Melzack & Wall, 1996; Turk & Melzack, 2010). Whilst pain is often liable to tissue damage, the feeling of pain is poorly related to the existence or the severity of such damage (Hadjistavropoulos, Breau, & Craig, 2010; McGrath, 1994; Melzack & Wall, 1965; Van Wilgen & Keizer, 2012). For example, individuals suffering pain from fibromyalgia show no tissue or nerve damage (Bellato et al., 2012). One mechanism that allows access to one's experience of pain is *communication,* by externalising individuals' internal feelings of pain and distress into words and/or actions and exchanging the information with other individuals (Craig, 2005, 2009, 2015; Hadjistavropoulos et al., 2011; Hadjistavropoulos & Craig, 2002).

1.2.1 Methods of pain communication

Pain can be communicated through verbal and nonverbal cues.

1.2.1.1 Verbal communication of pain

One of the key ways to find out if someone is in pain is to ask them. The fact that pain is subjective means that we are dependent on verbal expression of pain. Pain has once been described as "whatever the experiencing person says it is, existing whenever he says it does" (McCaffery, 1968, p. 95). Communication of pain has been benefited from the use of common language – an ultimate symbolic system shared and understood by the sender and the receiver (Burke, 1966). Human language has evolved to provide us with a set of sophisticated strategies to express one's painful feelings and allow others to have an insight into someone's internal experience of pain. In clinical environments, the self-report and self-rating of pain are the most widely used assessment methods and have been claimed as the "gold standard" of pain assessment (Engel, 1959; Katz & Melzack, 2011). These assessment tools provide insight into the quality of the painful feelings (e.g. throbbing, dull, aching), the affective feelings (e.g. fear, punishment, tension), the magnitude (e.g. pain intensity), and the affected body parts (Anderson, 2001; Gift, 1989; Herr, Spratt, Garand, & Li, 2007; Jensen et al., 2006; Kerns, Turk, & Rudy, 1985; Melzack, 1975, 1987;).

Whilst being extremely informative, the self-report of pain still has limitations. First of all, the ability of verbal communication is not readily available for all the population. Some of the sufferers, who may not be able to verbally report their pain efficiently, are more likely to be undertreated, e.g. preverbal children, aged people with dementia, individuals with cognitive impairments (Craig, 2006; Prkachin, 2009), and critically ill patients (Voepel-Lewis, Zanotti, Dammeyer, & Merkel, 2010). The painful conditions of these people are more often misunderstood or receive inadequate treatment due to unclear or insufficient reports of pain (Hadjistavropoulos et al., 2010). In addition to this, the verbal report of pain is also vulnerable to deliberate control (Hadjistavropoulos et al., 2011; Prkachin, 2009). Self-reports that heavily rely on conscious processing and cognitive mediation could be intentionally suppressed or exaggerated for different purposes or reasons. For example, aged people tend to understate their pain because of the fear of facing the consequences (e.g. need for hospitalisation, diagnosis of severe health problems) and losing independence (Herr & Garand, 2001). Children may overstate the pain (e.g. stomach ache) for staying at home from school when they believe that their absence will be allowed if the pain is intense (von Baeyer, 2009). Therefore, by considering these limitations, alternative methods are needed for pain communication.

1.2.1.2 Nonverbal communication of pain

Alongside verbal reports of pain, there are also nonverbal mechanisms, through which behavioural and/or vocal signals are exchanged between individuals. Pain can be communicated through multiple nonverbal channels, such as facial expressions, body movements and postures, and vocalisation (Harrigan, Rosenthal, & Scherer, 2005). When experiencing pain, there are often accompanied behaviours, including distinct changes of facial expression, covering or rubbing the affected body parts, avoidance behaviours, and groan or crying. These pain-related behaviours are exhibited in various manners and primitively serve slightly different functions (Prkachin, 1986). For example, the facial expressions and vocalisation are primarily for signalling the pain experience and seeking help (Williams, 2002). Besides signalling pain to others, the body movements and the avoidance behaviours related to pain are primarily adaptive that control the immediate situation, protect the affected body parts from further injury, and reduce the pain (Walsh, Eccleston, & Keogh, 2014). However, in social environments, all of these expressions and behaviours serve a communicative function, which encourages caregiving and alerts others about potential harms in the environment.

These observed nonverbal signs have also been used as important pain indicators and supplemental assessment tools in clinical environments (Feldt, 2000), in particular for paediatric patients (Schiavenato, 2008; von Baeyer & Spagrud, 2007) and elderly people (Herr, Bjoro, & Decker, 2006; Herr, Coyne, et al., 2006; Zwakhalen, Hamers, Abu-Saad, & Berger, 2006). These nonverbal expressions are useful tools, as they indicate not only the existence of pain, but also the level of severity and distress (Kunz, Lautenbacher, LeBlanc, & Rainville, 2012; Rocha & Prkachin, 2007; Schiavenato, Butler-O'Hara, & Scovanner, 2011). Moreover, the nonverbal expressions have been considered as more direct reflections of painful experience, as they are believed to involve less deliberate control and cognitive mediation compared to verbal reports (Hadjistavropoulos et al., 2011).

Relying solely on nonverbal cues for the assessment of pain is challenging, as the nonverbal expressions are mostly spontaneous and unrepeatable. Information loss, understanding conflicts, and interpretation interferences are likely to occur to degrade the nonverbal communication of pain. Though the verbal report of pain is considered less ambiguous than nonverbal cues, communicating pain through language is also complex and affected by a number of factors, such as message clarity, characters of sufferer and observer, and social contexts. Therefore, for more effective pain assessment, a combined approach of verbal and nonverbal communication is recommended (Turk & Melzack, 2010). More importantly, models and frameworks have been developed to organise the components and contexts of pain communication and study the mechanisms underlying the verbal and nonverbal communication of pain.

1.2.2 Models of pain communication

A series of models have been proposed to provide frameworks for the communication of pain (Craig, 2009, 2015; Hadjistavropoulos et al., 2011; Hadjistavropoulos & Craig, 2002; Hadjistavropoulos et al., 2004; Prkachin & Craig, 1995). Models of pain communication tend to be derived from Rosenthal's (1982) general communication model (i.e. the A→B→C model), in which communication was considered as information transmission from internal experience (A) through behaviours and language (B) to interpretation (C). Accordingly, the key components of pain communication are a sufferer's internal experience of pain (A), his/her report and/or expressions of pain experience (B), and an observer's assessment and interpretation (C). The process of generating behaviours and language to express the internal experience is called *encoding* (A→B), which occurs within the suffering person; and the process of interpreting the sufferer's expressions is called *decoding* (B→C), which happens between the sufferer and the observer (Rosenthal, 1982).

Whilst all the models of pain communication have the basic structure similar to Rosenthal's formulation, early applications of the models focus on different aspects of pain communication, such as communication through facial expressions (Prkachin & Craig, 1995), and differences between self-report and observational measures (Hadjistavropoulos & Craig, 2002). More recently, two comprehensive models of pain communication were proposed – the social communication model of pain (Craig, 2009, 2015) and the biopsychosocial formulation of pain communication (Hadjistavropoulos et al., 2011). Both models provided inclusive frameworks to organise and understand the biological, psychological, and social components of pain communication.

1.2.2.1 Social communication model of pain

The social communication model of pain (Craig, 2009, 2015; Hadjistavropoulos et al., 2004) proposed an integrated theoretical framework for pain communication, which characterised pain communication as a social phenomenon and considered the dynamic interplay among multiple biological, psychological, and social features and their influences on each step of communication. In the social communication model, the two parties of pain communication are the suffering person and the potential caregiver, for both of whom a sequence of components are included. The sufferer's components include the anticipation of pain, pain experience, and expression; and the potential caregiver's components are decoding of the sufferer's pain expression and delivery of actions. These components occur and interact with each other in a time sequence in pain communication, and the intrapersonal and interpersonal factors affect each component for both the sufferer and the caregiver. For example, the sufferer's experience of pain and the expressions are affected by personal history (i.e. intrapersonal) and current surroundings (i.e. interpersonal); and the caregiver's decoding is influenced by professional knowledge (i.e. intrapersonal) and the relationship with the sufferer (i.e. interpersonal).

The social communication model is featured by the integration of both intrapersonal and interpersonal influences into different processing stages of pain communication. Moreover, the social communication model is for general communication of pain in both clinical and social environments, which includes both verbal report and nonverbal expressions. Whilst informative and comprehensive, the model does not intensively explore the distinction between verbal and nonverbal communication. The verbal and nonverbal aspects of communication share common components (e.g. encoding and decoding process; sufferer and caregiver/observer), but the underlying mechanisms may differ from each other. For example, different levels of deliberate control and motivation may be involved. The verbal report of pain is an action involving intentions to describe and explain the internal experience explicitly and aiming to seek understanding, help, or caregiving; whereas the nonverbal expression is more likely to be unintentional and involves reflexive and automatic behaviour or expressions elicited by pain spontaneously. In the biopsychosocial formulation of pain communication (Hadjistavropoulos et al., 2011), the possible distinction between verbal and nonverbal communication of pain is discussed in a more thorough manner.

1.2.2.2 Biopsychosocial formulation of pain communication

The biopsychosocial formulation (Hadjistavropoulos et al., 2011) delineates an inclusive framework for pain communication by evaluating the steps of sufferers' internal experiences of pain and message encoding, and observers' decoding of the pain message and responses. In comparison to the social communication model, this biopsychosocial formulation provides a more fine-grained consideration of the basic biological and psychological processes and mechanisms underlying each step.

More importantly, the biopsychosocial framework highlights different mechanisms underpinning the verbal and non-verbal communication of pain in both encoding and decoding processes. The verbal and nonverbal messages of pain are encoded by different mechanisms. The encoding of verbal reports is a deliberate process relying on cognitive executive mediations, such as attention, memory and intentional use of language. The encoding of non-verbal expressions, however, relies mostly on automatic processing and involves little cognitive control. For example, newborns and elderly people with cognitive impairments have limited ability to communicate pain verbally but show facial expressions accompanying pain in a similar way to healthy adults (Prkachin, 2009).

In terms of decoding, sufferers' verbal messages of pain experience may be easier to interpret than nonverbal cues, primarily because of the clarity of the message and the context in which the communication takes place. *First*, the decoding of nonverbal expressions requires more attentional processes than verbal messages. Verbal communications often happen between two individuals or groups, where the context is possibly predetermined, and observers are attentive to sufferers' message. For example, in clinical environments, health professionals would expect patients to report their pain and distress. However, the environment of nonverbal communication is not preselected, and the nonverbal signals are broadcast into social environments rather than being delivered directionally. Therefore, as the first step to decoding nonverbal expressions, observers need to detect the "signal" (i.e. pain) and discriminate it from "noises" (i.e. other non-noxious expressions). *Second*, the verbal messages of pain benefit from the use of common language that is shared and understood by sufferers and observers, whereas nonverbal expressions rely heavily on observers' interpretation and require meanings to be attached to the expressions. *Additionally*, the observers may play different roles in the verbal and nonverbal communication of pain and provide different responses to the sufferers. In the context of communicating pain through verbal messages, the role of the observers is more predictable and most likely potential caregivers or whoever would attend to the sufferers' pain. However, the potential observers or onlookers of nonverbal pain expressions are less predictable (e.g. neutral, benevolent, or malevolent) and may accordingly provide more diverse responses (e.g. self-centred, prosocial, or punishing). Therefore, in the biopsychosocial formulation, three key elements of the *decoding* of nonverbal expressions are identified: detection and discrimination of available information (attentional processes to pain in others), attachment of the meaning to what has been observed (estimation of others' pain), and the behavioural and emotional responses of the observer.

In sum, both the social communication model and the biopsychosocial formulation provide a comprehensive account of the communication aspect of pain in social contexts and consider the key components as encoding and decoding of pain messages and the possible influences of intrapersonal and interpersonal factors. This thesis will take a social communication approach and experimentally investigate how one's pain is identified by others. Among many different types of cues (i.e. verbal and nonverbal) expressing pain, my research will focus on one particular type of nonverbal cues – facial expressions, where most research work has been conducted. Thus this thesis will also build on the basis of the biopsychosocial formulation, which highlights the distinction of nonverbal pain communication and the key elements of encoding and decoding of nonverbal expressions. Whilst these models tend not to include sex as a factor, there are sex differences in nonverbal communication and emotion recognition (Hall, 1978, 1990; Keogh, 2014; Kret & De Gelder, 2012). Therefore, I will also look at observers' sex differences as a secondary question. In the next section, I will present evidence for pain communication through facial expressions, which is the key focus within my PhD.

1.3 Communicating pain through facial expressions

Facial expression is a primary channel for nonverbal communication of pain that serves to externalise the internal pain experiences to facial actions and broadcast the signals of pain to the social world, but not directly modulate the pain. The encoding of facial expressions of pain is extremely efficient and does not require learning, which makes it a useful method for most of the population, in particular, those who have difficulties in verbal communication (Prkachin, 2009). Moreover, the facial expressions are readily observed (Ekman, 2006) and attract attention in the social environment (Bradley et al., 1997), which makes it a dominant nonverbal method of pain communication.

1.3.1 The prototypic facial expression of pain

The facial expressions tend to be the most popular topic within nonverbal pain communication research. This is possible because facial expressions communicate not only pain but also non-noxious emotions. There has been considerable work on facial expressions of emotions, which is closely relevant to the study of pain expressions. There is a set of very well developed methods, which were initially established to investigate facial expressions of emotions, and now could be adapted to explore how we communicate pain through faces. One of the most notable methods is the Facial Action Coding System (FACS; Ekman & Friesen, 1978).

FACS is an anatomically based measurement system that analyses the movement of a series of discrete facial muscular units and identifies an expression as a unique combination of a series of action units (Ekman & Rosenberg, 2005). For example, the facial expression of happiness could be coded as a combination of cheek raising and lip corner pulling (Ekman & Friesen, 2003). The FACS has been widely used to identify the facial action units of a variety of emotional expressions, including the basic emotions of anger, disgust, fear, happiness, sadness, and surprise (Ekman, Friesen, & Ellsworth, 1972), more socially complex emotions of embarrassment, pride, and shame (Tracy, Robins, & Schriber, 2009), and blended emotions (e.g. happily surprised; Du, Tao, & Martinez, 2014). Therefore, one of the key questions to ask here is whether it is possible to describe facial expressions accompanying pain using facial action units. If this is possible, it would suggest that pain may share similar mechanisms with other physiological and affective states (e.g. core emotions), in terms of encoding internal feelings into facial behaviours.

Researchers discovered a consistent pattern of facial movements that is unique to pain experiences, including brow lowering, tightening and closing of the eyelids, nose wrinkling, and upper lip raising (Craig, Hyde, & Patrick, 1991; Craig & Patrick, 1985; LeResche, 1982; LeResche & Dworkin, 1988; Patrick, Craig, & Prkachin, 1986; Prkachin, 1992b; Prkachin & Mercer, 1989). Although a number of other facial movements may also occur during pain and vary slightly due to the type of stimuli and pain intensity (Prkachin, 2009), these four facial actions have been found consistent across different modalities of lab-induced pain (i.e. electric shock, cold, pressure, and ischemia; Prkachin, 1992b) and some clinical pain (e.g. shoulder pain; Prkachin & Solomon, 2009). The expressiveness and duration of the actions could effectively indicate the pain intensity level and correlate with sufferers' self-report (Kunz, Mylius, Schepelmann, & Lautenbacher, 2004; Prkachin & Solomon, 2009). Therefore, the four facial musculature movements are identified as core action units of the facial expressions of pain, which is of great significance for nonverbal pain assessment (Prkachin, 2009) and the creation of prototypic facial stimuli of pain (Simon, Craig, Gosselin, Belin, & Rainville, 2008).

1.3.2 Encoding of facial expressions of pain

Research has also been conducted to investigate how pain experiences are encoded through facial expressions, and a series of questions generated.

1.3.2.1 Is encoding of pain an innate ability?

One question that has been asked is whether pain encoding is innate, and one way of exploring it would be to look at pain expressions in newborns and congenitally blind individuals. By analysing the newborn infants (Grunau & Craig, 1987) and preterm newborns' facial expressions (Craig, Whitfield, Grunau, Linton, & Hadjistavropoulos, 1993; Stevens, Johnston, & Horton, 1994), it has been found that young babies could show pain expressions when experiencing acute tissue damage (e.g. heel lance for blood sampling) at a very early stage of development, for example, 40 hours after birth, which is believed to be before the opportunity to learn response patterns. More recent research found that healthy foetuses at a gestational age of 24 to 32 weeks could show characteristic facial actions related to pain or distress, though these facial movements are not as complex as newborn babies' (Reissland, Francis, & Mason, 2013). These findings suggest that the ability to express pain may develop as the foetal stage progresses and is available from the earliest stage of life. Moreover, similar to emotional expressions (Fridlund, 2014; Matsumoto & Lee, 1993), congenitally blind individuals could also express pain and physical distress through facial expressions, though the sensitivity of encoding different pain intensities is lower than sighted people (Kunz, Faltermeier, & Lautenbacher, 2012). This finding also suggests that expressing pain through the face may have an innate quality, but the ability to express pain might be improved by learning to a more sophisticated level.

1.3.2.2 Is pain expression consistent across population?

The encoding of core facial actions of pain is found consistent across ages and sex. Although facial expressions could be influenced by multiple individual and sociocultural factors (Craig, Prkachin, & Grunau, 2010), the morphology of the core pain expression is consistent across lifespan from newborns to elderly people (Craig et al., 2010; Kunz, Mylius, Schepelmann, & Lautenbacher, 2008; Williams, 2002). In addition to this, although females and males may perceive pain differently (Mogil & Bailey, 2010; Wiesenfeld-Hallin, 2005), they seem to encode pain experience into facial expressions in a similar way (Kunz et al., 2008). However, it has not been confirmed whether the pain expressions are universal across different cultures and ethnicity groups or not. One early study compared the 2-month old healthy Canadian-born Chinese and non-Chinese babies' facial expressions of pain during routine immunisation and found only one of seven facial characteristics was different between the two groups (Rosmus, Johnston, Chan-Yip,

& Yang, 2000). However, there is little evidence on adults' expressions. This may be primarily because of the difficulties in finding adults in different cultural groups that have never been exposed to other cultures (Williams, 2002).

1.3.2.3 What aspect of pain is encoded in facial expressions?

Another question that has been asked about the encoding of pain is what aspect of pain experiences is encoded in the face. The experience of pain is multidimensional, involving not only the sensory (e.g. pain intensity) but also the emotional dimension, which refers to the unpleasant, distressful, and negative affect-related experiences inherent to pain (Hale & Hadjistavropoulos, 1997; Melzack & Casey, 1968; Mounce, Keogh, & Eccleston, 2010; Williams & Craig, 2016). The facial expression of pain is a multidimensional response system, which encodes both sensory and emotional aspects of pain experience, e.g. facial actions around the eyes encoding the sensory quality, and the actions of the eyebrows and the upper lip encoding the emotional quality (Kunz et al., 2012). Moreover, the expressiveness/intensity of these facial actions is associated with the severity of pain experiences measured by self-report (Kunz et al., 2008; Prkachin, 2009; Rahu et al., 2013; Schiavenato et al., 2011), in terms of the sensory intensity and the emotional unpleasantness (Kunz et al., 2012; Rocha & Prkachin, 2007; Schiavenato et al., 2011). This association between facial action expressiveness and pain intensity has also been used in the automated estimation of pain severity and machine learning (e.g. Kaltwang, Rudovic, & Pantic, 2012; Werner, Hamadi, & Niese, 2014).

In sum, the encoding of facial expressions of pain is an efficient and informative process that has an innate quality and is readily available from an early stage of life. The encoding of core facial actions of pain seems to be consistent across different modalities of pain and reliable across the lifespan for both men and women. However, no conclusive evidence was shown for the consistency across cultures. Finally, the evidence is strong that facial expressions of pain are informative, which encode both sensory and emotional qualities of pain experience and indicate the level of intensity.

1.3.3 Decoding of facial expressions of pain

Communication is a two-way process, containing not only the encoding process but also a paired counterpart, namely decoding (i.e. the process of interpreting the sufferer's facial expressions). Thus, it is important to know whether we can decode others' pain expressions accurately and how we perceive the pain expressions. Facial expressions of pain could be decoded in different manners. This section will introduce the decoding of facial expressions of pain in terms of facial action analysis and observer's judgement.

1.3.3.1 Decoding using FACS

The facial expressions of pain could be decoded by analysing the facial actions using FACS. Although this was claimed as an extremely informative and sophisticated method of pain assessment (Prkachin, 2009), decoding of pain expressions using FACS has been used mostly for research purposes (e.g. Ekman & Rosenberg, 2005; Kunz, Rainville, & Lautenbacher, 2011; Lautenbacher, Niewelt, & Kunz, 2013; Lilley, Craig, & Grunau, 1997; Prkachin, Berzins, & Mercer, 1994) and only to some extent for clinical assessment (e.g. Chang, Versloot, Fashler, McCrystal, & Craig, 2015; Hadjistavropoulos, Chapelle, Hadjistavropoulos, Green, & Asmundson, 2002; Peters et al., 2003; Schiavenato, 2008). This is because the FACS analysis is incredibly time-consuming and requires extensive training of the coders. As a result, this method is mostly used in analysing photographs or pre-recorded video clips of the pain faces by trained coders. In order to overcome these limitations, recently developed automated facial expression analysis software employs FACS to decode the pain faces and achieves good accuracy, though not highly efficient (e.g. Ashraf et al., 2009; Bartlett, Littlewort, Frank, & Lee, 2014; Hamm, Kohler, Gur, & Verma, 2011; Lucey et al., 2011).

It is noteworthy that analysis of facial action units may be different from how we process other's facial expressions to identify pain in daily life or social environments. For example, without the knowledge of FACS, parents can identify whether their children are in pain or not and estimate the severity by just giving a glance at their children's faces (Larochette, Chambers, & Craig, 2006; Loopstra, Strodl, & Herd, 2015). In this case, the facial expression may not be analysed as a series of action units but processed as a whole (Calder, Young, Keane, & Dean, 2000; Richler, Mack, Gauthier, & Palmeri, 2009). Though it is not always as accurate as fine-grained analysis of facial action units, processing faces in a global manner is verified as a very efficient method to decode pain expressions (Czekala, Mauguière, Mazza, Jackson, & Frot, 2015) and plays a vital part in the social communication of pain. Thus, one stream of research on the decoding of pain expressions focuses on observer's decoding of pain expressions.

1.3.3.2 Observer's decoding

An alternative to FACS is to consider the face as a type of object that we encounter in daily life. In everyday visual scenes, it is believed that we process faces in a holistic manner rather than a collection of isolated features (Bruce & Young, 1986; Omigbodun & Cottrell, 2013; Tanaka & Farah, 1993; Tsao & Livingstone, 2008; Young, Hellawell, & Hay, 1987). Without the knowledge of FACS, observers are able to decode facial pain expressions on an acceptable level of accuracy for multiple purposes. Studies on observer's decoding of facial expressions of pain have focused on (1) observer's sensitivity to the authenticity of pain expressions (i.e. whether the expressions are genuine or simulated/faked) and value judgements (i.e. whether the expressions are suppressed or exaggerated), and (2) the estimation of the level of pain severity.

a. Judgement of authenticity

Facial expressions have been considered as having higher credibility compared to verbal reports of pain, as they are less prone to voluntary control and largely automatic reflexive responses to pain experience (Craig, 1992; Prkachin, 2009). However, it has also been found that facial expressions of pain can be controlled through, for example, suppressing, exaggerating, and even simulating in the absence of pain if instructed so (Badali, 2000; Kleck et al., 1976; Larochette et al., 2006; Vervoort et al., 2008), though to a much smaller extent than verbal reports (Prkachin, 2005). Thus observers' ability to detect the deliberate control and/or deception in facial expressions of pain has been examined.

For suppressed pain expressions, untrained observers could only identify them at a relatively low accuracy level, and tended to believe that sufferers who suppressed their pain expressions were experiencing less pain than those who faked or exaggerated the expressions (Boerner, Chambers, Craig, Riddell, & Parker, 2013; Larochette et al., 2006; Poole & Craig, 1992). In comparison, observers tended to show higher detection sensitivity to faked or simulated pain expressions. This may be because we are more likely to suppress pain expressions in natural environment to avoid showing weakness to strangers or antagonists (Badali, 2000; Kleck et al., 1976; Williams, 2002), and accordingly are "expert" at hiding pain than faking pain, which makes the detection of suppressed expressions a more challenging task compared to the detection of faked or simulated expressions. For example, children at 8-to-12-year-old could successfully suppress their pain expressions to baseline level (i.e. not painful), whereas when being instructed to fake pain expressions, their facial action movements deviated significantly from genuine pain (Larochette et al., 2006).

Whilst more accurate, the detection of faked or simulated pain expressions is also affected by multiple factors, such as the type of pain and the observer's experiences and sex. Prkachin (1992a) examined whether observers (i.e. undergraduate students) could distinguish between genuine and simulated facial expressions of lab-induced electric stimulation pain, and found that observers were able to distinguish them at a modest accuracy level. However, untrained observers were not able to distinguish genuine and simulated pain expressions of chronic pain patients, and rated the faked expressions of pain more intense than the genuine ones (Poole & Craig, 1992). This may be because when faking or exaggerating pain expressions, the patients tend to show a larger number of more tensed facial actions, both pain-related and unrelated, and a longer peak intensity and overall duration compared to genuine pain expressions (Hill & Craig, 2002; Ruben & Hall, 2016), which might be misunderstood as reflecting high intensity of pain by untrained observers. Fortunately, the observers' ability to detect genuine and simulated pain expressions could be improved by deception training and immediate corrective feedback (Hadjistavropoulos, Craig, Hadjistavropoulos, & Poole, 1996; Hill & Craig, 2004). This has been supported by studies comparing the detection sensitivity among different observers. For example, though children's faked pain expressions could be detected by parents (Larochette et al., 2006), they were not as accurate as those made by paediatric nurses (Boerner et al., 2013). This may be because nurses had more experience of interpreting a broad range of children's pain expressions than parents and could receive constant and extensive feedback to shape their understanding of children's pain and expressions.

The sex of the observer might also affect the detection of deception in facial expressions of pain (Hill & Craig, 2004; Keogh, 2014; Ruben & Hall, 2013). Hill and Craig (2004) found females were more accurate than males at judging the authenticity of pain expressions (i.e. distinguishing genuine, faked, exaggerated, suppressed pain, and neutral expressions), whereas Ruben and Hall (2013) found higher accuracy for male observers than females. In contrary to these findings, an earlier study found no difference between male and female observers in the judgement of authenticity of facial expressions of pain (Poole & Craig, 1992). These findings suggest that sex differences in the detection of deception or judgement of authenticity of pain expressions are not consistent, and so interpretations remain speculative (Keogh, 2014; Ruben & Hall, 2013).

b. Estimation of intensity

In addition to deception in pain expressions, we are also sensitive to different intensities of other's pain expressions (Danziger, Prkachin, & Willer, 2006; Deyo, Prkachin, & Mercer, 2004; Prkachin, 2011; Prkachin & Rocha, 2010). This sensitivity is shown from a very early age of 5-to-6-year old that children could differentiate strong and moderate intensity pain expressions and does not stop developing until 11-to-12-year old that subtler differences between low and moderate intensities could be differentiated, which is similar to adults (Deyo et al., 2004). Moreover, individuals with congenital insensitivity to pain could differentiate the intensities of other's pain expressions as accurately as healthy individuals (Danziger et al., 2006). These results suggest that we are sensitive to other's facial pain expressions and able to differentiate the severity of pain from expressions. In addition, observers' sex seems to play a role as well. It has been found that females showed a higher sensitivity than males, in particular to expressions of pain at moderate intensities (Prkachin, Mass, & Mercer, 2004).

However, a distinction is needed to be made between the sensitivity to *differentiate* the expression intensity and the ability to *estimate* other's pain intensity through facial expressions. Differentiation of expression intensities could be made by comparing the expressiveness of pain faces and assigning them to appropriate category of the intensity levels, e.g. mild, moderate or strong; whereas the estimation of other's pain intensity is more complex and requires a thorough understanding of the sufferer's internal painful experience through his/her facial expressions (Prkachin, 2011).

Although we show high sensitivity to different pain expression intensities, our estimation of other's pain severity is not always accurate. When compared with the painful levels reported by sufferers themselves, untrained observers (i.e. university students; Prkachin et al., 1994; Pronina & Rule, 2014) and health professionals (Kappesser, Williams, & Prkachin, 2006; Prkachin, Solomon, & Ross, 2007) both tend to underestimate the sufferers' pain intensities. For example, in Prkachin and colleagues' study (1994), observers were asked to view video clips of sufferers' facial expressions when experiencing shoulder pain and rate their pain intensity levels on the same scale as those used by sufferers themselves. However, the observers systematically underestimated sufferers' pain by 50-80% compared to sufferers' self-report. There are also potential sex differences. When considering the effect of the observer's sex, it was found that males tend to underestimate the observed pain intensity to a greater extent than females, e.g. 8–10 points lower on a 100-point scale (Robinson & Wise, 2003).

Moreover, it has been found that health professionals tend to underestimate sufferer's pain severity to a greater extent compared to those who do not work in the clinical environment (Prkachin, Solomon, Hwang, & Mercer, 2001). The exposure to vicarious pain, in particular, those of high intensities, would bias health professionals' judgement and lead to underestimation of sufferers' pain (Prkachin, Mass, & Mercer, 2004; Prkachin & Rocha, 2010). Researchers tried to explain this inflated underestimation by using the adaptation-level theory (Helson, 1964) and argued that whoever exposed to frequent and intense pain expressions would adjust their standard to a relatively high level and accordingly underestimate the pain intensity when evaluating new expressions (Prkachin, 2011; Prkachin et al., 2004; Prkachin & Rocha, 2010). However, the families of chronic pain patients, who also expose to frequent and intense pain expressions, tend to attribute greater pain intensities to sufferers than those who do not have families in chronic pain (Prkachin et al., 2001).

As a matter of fact, it has been found that observers are more likely to underestimate the pain of patients they dislike than the ones they favour (Ruddere et al., 2011). Thus, the exposure to pain expressions may not be the only one contribution to the underestimation, but more complex mechanisms may be involved (Courbalay, Deroche, Prigent, Chalabaev, & Amorim, 2015; Lautenbacher, Hofer, & Kunz, 2015; Martel, Thibault, Roy, Catchlove, & Sullivan, 2008; Pronina & Rule, 2014). Also, it is unclear why people without extensive exposure to pain expressions or injuries systematically underestimate others pain to a large extent (i.e. 50-80%). Prkachin et al. (1994) proposed that observers might make insufficient use of information that is available in sufferers' facial expressions, and accordingly underrated sufferers' pain severity. However, this has not been systematically studied yet, and it remains unclear what information is used by observers to decode a pain face.

Overall, the evidence is strong for observers' sensitivity to different intensities of others' pain expressions. The estimation of others' pain severity through their facial expressions is, however, less accurate, where both naïve observers and health professionals tend to underestimate others' pain to a large extent comparing to self-report. When judging the authenticity of pain expressions, observers are able to detect the faked or exaggerated expressions of pain to a higher accuracy level than the suppressed expressions. In addition to these abilities, being able to detect pain from facial expressions and differentiate it from other non-noxious expressions is also an important mechanism of the decoding process and key to successful communication of pain, in particular in social environments, where contextual cues (e.g. patients in clinical settings) that facilitate the recognition of pain are not available.

1.4 Recognition of pain from facial expressions

Facial expressions convey a wealth of signals of various internal experiences, such as pain and emotions. Being able to differentiate pain from other emotional expressions unambiguously is fundamentally important in social communication. During the face-to-face encounters in daily life, we constantly watch others' facial expressions and try to infer what the expression signals, pleasantness or sadness, threat or need of help. This is different from the clinical environment or research settings, where observers are instructed to decode a single "pain" expression, in terms of judging whether someone is in pain or not, and estimating how severe it is. In social environments, being able to efficiently detect and accurately interpret what an expression is showing is of primary importance, for example, helping behaviours will not be delivered without knowing someone is in pain. The current thesis will take a social communicative approach and study how others' pain is recognised from their facial expressions. Here, I will present evidence for pain recognition, in terms of differentiating expressions of pain from other non-noxious emotions.

1.4.1 Categorical vs. multi-dimensional view

Usually, differentiation of pain from emotional expressions is studied from two perspectives: Whether pain expressions are able to be accurately identified as a distinct category (*categorical view*); and how pain expressions are interpreted in terms of valence and arousal (*multi-dimensional view*).

According to the categorical view, observers are assumed to be able to perceive others' discrete emotional states through their facial expressions and assign the emotional states into appropriate categories (Ekman & Cordaro, 2011; Ekman, 1992; Levenson, 2011; Panksepp & Watt, 2011). For example, by seeing a face showing a smile with mouth corners pulled up and backwards, cheek raising, and wrinkles around the eyes, an observer should readily perceive the emotion of happiness (Ekman, Friesen, & Hager, 2002). Studies adopting the categorical view typically consider six core expressions showing emotions of anger, disgust, fear, happiness, sad, and surprise (Ekman et al., 1972) and examine observers' ability to recognise emotions through facial expressions by measuring the recognition accuracy. It has been found that, in general, happiness is recognised more accurately and faster than other emotions, followed by surprise, anger, and sadness, with the poorest accuracy and longest latencies for fear and disgust (Calder et al., 2000; Calvo & Lundqvist, 2008; Calvo & Nummenmaa, 2009; Palermo & Coltheart, 2004; Recio, Schacht, & Sommer, 2013; Simon et al., 2008; Tottenham et al., 2009).

By taking a categorical view, studies on pain recognition examined the recognition accuracy of pain expressions and compared with core emotions. It has been found that one's pain experiences could be recognised from his/her facial expressions and accurately differentiated from other non-noxious emotions (70%). The accuracy is comparable to fear and disgust, but not as accurate as happiness, surprise, or anger (hit rate around 80%; Kappesser & Williams, 2002; Reicherts et al., 2012; Simon et al., 2008). More importantly, recent studies found that we are able to recognise pain from facial expressions even in challenging viewing conditions. For example, when observers could only view the face stimuli for 100-200 ms, they were able to recognise pain accurately from facial expressions (80%), which is even more efficient than gender discrimination (Czekala et al., 2015). Moreover, expressions of pain could even be recognised and differentiated from core emotions with limited facial areas available (e.g. eyes, mouth; Roy, Blais, Fiset, Rainville, & Gosselin, 2015), though at a moderate accuracy level (mean accuracy around 56%). Though the accuracy varies depending on the task parameters in different studies, the evidence is strong that we are able to recognise pain from facial expressions and sensitive to such signals of others' pain experiences. However, few types of research have investigated *how* we recognise facial expressions of pain.

In contrast to the categorical view, another stream of research considers facial expressions in a multi-dimensional view, which believes that all the expressions could be analysed along an affective continuum on two orthogonal dimensions of valence (i.e. pleasantness) and arousal (i.e. excitingness; Barrett, 2006; Lindquist & Gendron, 2013; Russell, 1994). For example, happy expressions are rated as highly pleasant and relatively calming, whereas expressions of sadness are moderately unpleasant and relatively arousing, (Balconi, Vanutelli, &

Finocchiaro, 2014; Lang, Greenwald, Bradley, & Hamm, 1993; Zald, 2003). By taking a multi-dimensional view, facial expressions of pain are perceived as being extremely unpleasant and highly arousing (González-Roldan et al., 2011; Reicherts et al., 2012; Simon et al., 2008; Simon, Craig, Miltner, & Rainville, 2006).

While both approaches (i.e. expression categorization and valence and arousal rating) are adopted and provide insights into observers' perception of pain expressions, this thesis will take the categorical view and investigate how observers recognise pain and differentiate it from emotional expressions in terms of categorization. This is because the mechanism of expression recognition fits better with the categorical view. Recognition implies that the meaning could be attached to what has been observed by assigning the expression to a discrete, correct category of emotion or pain (Calvo & Nummenmaa, 2015). In contrast, the multi-dimensional view does not require a consensus on what has been observed but considers the interpretation of an expression on two affective dimensions (i.e. valence and arousal), where the "message" conveyed by the expression may be decoded ambiguously. For example, both pain and fear expressions are perceived as highly unpleasant and arousing (Reicherts et al., 2012; Simon et al., 2008), which is, however, inadequate to differentiate the two expressions effectively or elicit different responses, e.g. caregiving to the individual in pain.

1.4.2 Pain expressions vs. emotional expressions

Facial pain expressions share similar properties with expressions of core emotions. From the categorical view, like other discrete emotion types, the facial expressions of pain represent a distinct category of internal experiences and can be differentiated from other expressions. From the multi-dimensional view, the facial pain expressions could be interpreted in terms of valence and arousal to a comparable level as some negative emotions (e.g. fear; Reicherts et al., 2012; Simon et al., 2008). This may be because emotion is an essential component of pain experience, and fear (e.g. fear of pain from injury or insult) is one of the primary negative emotional components relevant to pain (Hale & Hadjistavropoulos, 1997; Mounce, Keogh, & Eccleston, 2010). On the other hand, pain also differs from other non-noxious emotions, as it consists not only the affective/emotional quality but also the sensory aspect of experience, which has a biological basis and may be relevant to actual or potential tissue damage (Merskey & Bogduk, 1994; Lumley et al., 2011). For example, the sensory dimension of pain encompasses the perception of the location, intensity, and the quality of pain (Melzack & Casey, 1968), however, none of these occur in other emotions. In terms of facial expression, both sensory and emotional components are encoded in pain expressions (Kunz et al., 2012); whereas only the affective/emotional qualities are encoded in the emotional expressions. It is thus of great interest to know whether the expressions of pain are decoded differently from non-noxious emotions as well. Therefore, this thesis will compare the recognition of facial expressions of pain with core emotions.

1.4.3 Sex differences

Observer's sex has also been postulated to play a role in expression recognition (Hall, 1978, 1990; Keogh, 2014; Kret & De Gelder, 2012). A number of studies found that females recognise (i.e. categorise) emotional facial expressions more accurately and/or faster than males (e.g. Hall & Matsumoto, 2004; Hall, Hutton, & Morgan, 2010; Hampson, Vananders, & Mullin, 2006; Montagne, Kessels, Frigerio, Haan, & Perrett, 2005; Thayer & Johnsen, 2000), in particular for negative expressions (e.g. anger and disgust; Campbell et al., 2002). Although sex of the observer is also proposed to affect the decoding of pain expressions (Keogh, 2014; Keogh & Holdcroft, 2002), in terms of the detection of deception (e.g. Hill & Craig, 2004) and estimation of pain intensity (e.g. Prkachin, Mass, & Mercer, 2004), sex differences in the recognition (i.e. categorization) of pain expressions have been systematically examined in few studies. Researchers studing facial expressions of pain from a multi-dimensional view have examined the role of the sex of the observer, and generaly found no consistent influence of the observer's sex on the interpretation of pain expressions in terms of the valence and arousal quality (Simon et al., 2008; Simon et al., 2006). It is thus of interest to know, from a categorical view, whether women and men recognise (i.e. categorise) pain expressions in a similar way or not. To date, few studies are designed to directly consider sex differences in nonverbal pain recognition. Therefore, this thesis will consider the role of the observer's sex in the recognition of pain expressions as well.

1.5 Main research questions and rationale

In sum, previous studies confirm that we can recognise others' pain from their facial expressions accurately and efficiently, even in challenging visual conditions. Our sensitivity to expressions of pain has an obvious survival value and suggests that a highly reliable and efficient decoding process may be involved. However, so far few types of research have investigated mechanisms underlying the recognition of facial expressions of pain, and we know very little about how pain is recognised from facial expressions and what makes the recognition possible. While the unpleasant and highly arousing nature of pain expressions may be relevant to our sensitivity and even attentional bias towards such expressions (Baum, Schneider, Keogh, & Lautenbacher, 2013), it is still unclear how information in facial expressions is processed and what cues are used to perceive the distinguishing quality of pain. This leads to the main research question of this thesis – how do we process facial expressions to make the recognition of pain possible?

This thesis, therefore, aims to investigate how we recognise others' pain from their facial expressions. Facial expressions are a primary nonverbal channel of pain communication and so need to be clearly and unambiguously recognised. Recognition studies of pain expressions have typically focused on observers' performance of recognition and/or prediction of another's pain. The evidence is strong that pain can be recognised from facial expressions to an acceptable accuracy level in an efficient manner, even in challenging viewing conditions. It is therefore of great interest to know how pain expressions are recognised and what mechanism is underpinning this process.

There are different sources of information available (e.g. affective qualities), which are thought to reflect some of the underlying mechanisms involved in the processing of pain expressions. One approach is to consider the facial expressions of pain as a type of visual stimulus and investigate how human perceptual processes contribute to the recognition of pain expressions and what makes the visual percept of pain expressions possible. It is, therefore, important to consider what is involved in this visual perceptual process, for example, what information is available in facial expressions, what information is utilised by observers, whether this information is characteristic for pain, and how we process the information to recognise pain expressions. These raised questions and the context in which perceptual processes of facial expressions are studied will be further discussed in Chapter 2.

Chapter 2 An introduction to spatial frequency information and spatial frequency information processing in the recognition of facial expressions

As introduced in Chapter 1, pain experience can be detected from a person's facial expressions and differentiated from non-noxious emotional states. However, it is still unclear how facial expressions are processed by observers to make the recognition of pain possible. To explore this question, this thesis will take a visuoperceptual perspective and investigate how pain expressions are recognised in terms of perceptual information analysis. One type of fundamental perceptual information is spatial frequency (SF) information, which encodes the amount of detailed information and determines the appearance of a visual display. For a facial expression, low-SF information encodes the large-scale facial configuration and structural changes, and high-SF information encodes the fine-detailed facial features and abrupt edge changes. This thesis, therefore, examines how different perceptual information is processed and contributes to the recognition of pain expressions.

2.1 Why is SF information important?

The typical method of analysing a unique set of facial codes does not provide complete insight into the observers' decoding process. This is because, in visual scenes, faces are believed to be processed dominantly in a holistic manner as an integral of the whole face area rather than a selection of isolated units (Bruce & Young, 1986; Cheung, Richler, Palmeri, & Gauthier, 2008; Farah, Wilson, Drain, & Tanaka, 1998; McKone, Kanwisher, & Duchaine, 2007; Omigbodun & Cottrell, 2013; Piepers & Robbins, 2012; Richler, Gauthier, Wenger, & Palmeri, 2008; Tanaka & Farah, 1993; Tsao & Livingstone, 2008; Young et al., 1987), at least for faces in the upright position (McKone et al., 2013; Taubert, Apthorp, Aagten-Murphy, & Alais, 2011) or early perception (Richler et al., 2009). Moreover, analysis of facial action units is extremely time-consuming and requires extensive training, but untrained observers (i.e. student participants) were found to be able to recognise pain from facial expressions accurately (80%) by viewing the face for only 100 ms (Czekala et al., 2015), which is inadequate to analyse the facial musculature movements. It is therefore of great interest to know what is involved in the observers' decoding process, and what makes the recognition of pain expressions so efficient.

One approach is to consider the facial expressions as a type of visual stimulus we encounter in everyday visual scenes and investigate how we visually process facial expressions to recognise the "message" of pain. The visual perception of facial expressions has not been systematically studied within the context of pain communication. As mentioned at the end of Chapter 1, there are two fundamental questions need to be answered. First, if we deem facial expressions as visual stimuli, then what kind of perceptual information is carried in the faces to depict the expressions? Second, is the information obtained meaningful in terms of visual processing? This chapter will try to answer these questions by reviewing the existing evidence in the literature.

Besides the higher level social-cognitive features of faces and facial expressions, there are more basic attributes to the perception of a visual stimulus, such as size, colour, contrast, and SF (Hole & Bourne, 2010; Rolls, 2011). Of these, the SF is considered particularly important for the visual perception of faces and facial expressions, as different SFs encode different characteristic information about a face and facial expression (De Cesarei & Codispoti, 2013; Hole & Bourne, 2010; Rolls, Baylis, & Leonard, 1985; Rolls, 2011; Ruiz-Soler & Beltran, 2006). For example, high-SF information depicts the fine details about the features of a face, and low-SF encodes the large-scale structural information. Moreover, it has been widely accepted that, at an early stage of visual perception, our visual system extracts information from a visual stimulus in terms of SF components (Bullier, 2001; De Valois & De Valois, 1980; Shapley & Lennie, 1985) and analyses the visual input on multiple SF scales (Bar, 2004; Kauffmann, Ramanoël, & Peyrin, 2014; Skottun, 2015), the outputs of which constitute a basis for higher-level recognition or interpretation (Morrison & Schyns, 2001; Skottun, 2015; Thorpe, 2001). Thus a good understanding of the role of SF information is vital for comprehension of the higher level decoding of facial expressions. However, to date, the role of SF information has not been considered in the context of pain expressions. This thesis, therefore, aims to investigate the recognition of pain expressions in terms of SF information analysis. In the following section, I will provide an introduction to SF information, in terms of what spatial frequency is, the information it conveys, and how it is analysed in the visual system.

2.2 What is SF information?

2.2.1 Temporal vs. spatial frequency

Frequency is commonly referred to as temporal frequency, which is the number of occurrences an event repeats within a particular period of time. In science, particularly for periodical processes, one occurrence of a repeating event is termed as one *cycle*, and accordingly, *frequency* is the number of cycle per unit time (Boashash, 2003). For example, if one event occurs once every second, the frequency of this event is one cycle per second (i.e. 1 Hz). Similar to the concept of temporal frequency, *spatial frequency* (SF) refers to the number of occurrences of a structure repeating within *a unit space*. For example, in Figure 2-1a and 2-1b, the gratings[2] (i.e. light-dark bars) repeat three and six times respectively within the unit space. Therefore, the SF of gratings in Figure 2-1a is three cycles per unit space and Figure 2-1b six cycles per unit space. The gratings of higher SF is spatially denser and showing finer appearance than those of lower SF.

[2] These gratings are spatial periodic visual stimuli with sinusoidal luminance profile. They are considered as the most basic and convenient stimuli in visual perceptual research, as they are the simplest light distribution that, according to Fourier theory, could be used to express any light distribution in a retina image (Lamberto Maffei & Fiorentini, 1973).

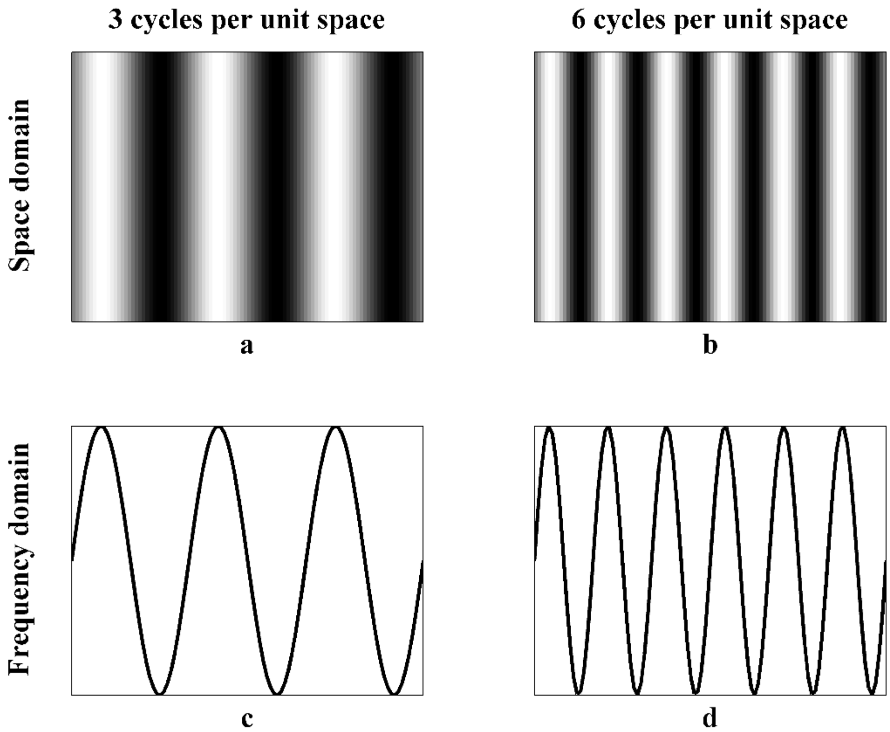

Figure 2-1 Gratings (a and b) and sinusoidal waves (c and d) of different SFs. a and b show gratings with the SF of three cycles and six cycles per unit space respectively. c and d show sinusoidal waves of the SF of three cycles and six cycles per unit space respectively. a and c are showing the same signal in two domains: the space domain and the frequency domain, respectively; and the same for b and d. The signals are transformed between the two domains using Fourier transform. The images were generated using MATLAB 2012.

There are two domains in which a visual stimulus could be presented – the *space domain* and the *frequency domain* (Bourne, 2010). In the space domain, an image presents itself in a normal way that we are familiar with. For example, in the space domain (Figure 2-1a and 2-1b), the gratings are presented as light-dark bars. In the frequency domain, the gratings are presented in the form of sinusoidal waves (Figure 2-1c and 2-1d), which are the one-to-one mapping of the original gratings in the space domain. The frequency of the sinusoidal waves represents the space occupied by the gratings, with low frequency reflecting large space and high frequency reflecting small space. The wave peaks and valleys represent high luminance (i.e. white bars) and low luminance (i.e. black bars) of the gratings respectively. The conversion between the space domain and the frequency domain could be achieved by Fourier transform (Gonzalez & Woods, 2009). Although the images mapped in the frequency domain are not as apprehensible as those in the space domain, the frequency domain is of particular interest in the area of image and visual processing, because it gives access to the basic visual attributes of a stimulus, e.g. the SF of an image, which could be assessed and manipulated in the frequency domain only.

2.2.2 Object SF vs. retina SF

For images, different SFs convey different information about the appearance in the space domain. For example, in Figure 2-2, appearances of the same image are different according to the SFs. The broad-SF image contains the full spectrum SF information and has a clear integral representation of the image content. In contrast, the low-SF and high-SF images are derived from the original image but only have limited visual information available. The low-SFs convey relatively large-scale coarse information and have a blurry appearance, whereas the high-SFs convey fine-detailed information and represent abrupt edge changes (as in Figure 2-2). In the space domain, the approximate SF spectrum (i.e. broad, low, or high) of an image could be inferred from the appearance, however, the precise SF range (i.e. the cut-off values) of the image is not possible to be identified. Thus, in experimental studies, images need to be converted from the space domain into the frequency domain to allow access to the image SF for assessment and manipulation. For details of image transformation and SF manipulation, please refer to Chapter 3 Section 3.3.

Figure 2-2 Images of broad-SF, low-SF, and high-SF from left to right. The broad-SF image is the original image, on the basis of which the low-SF and high-SF images are reconstructed. The low-SF image contains SFs < 8 cycles per image and the high-SF image contains SFs > 32 cycles per image. The original image is obtained from the STOIC database (Roy et al., 2007), and the permission to use and reproduce the images was granted by the copyright holder. The inclusion of example images in this thesis is permitted as well. The low-SF and high-SF images were produced using MATLAB 2012.

The SF that has been introduced above is *object SF* – a basic attribute of a visual stimulus (e.g. an image), which is measured by cycle per unit space (e.g.

cycle per image, or cycle per face). This SF is a constant, stimulus-based measure that refers to the level of detailed information presented and determines the appearance of an image (Parish & Sperling, 1991; Sowden & Schyns, 2006). In visual perception, there is another measure of SF, which is based on the image projected on the retina, namely *retina SF* (Parish & Sperling, 1991; Sowden & Schyns, 2006). The retina SF is measured in the cycle per degree of visual angle (cpd), which is calculated by dividing object SF by visual angle. For example, if each of the images in Figure 2-2 captures a visual angle of 4°, the SF cut-offs for the low-SF and high-SF images are 2 cpd and 4 cpd, respectively. The retina SF depicts the level of detail contained in the image projection on the retina. When the object SF is fixed, the retina SF varies with viewing distance, e.g. the increase of distance results in the decrease of retina SF. The object SF and the retina SF are supplementary measures that can be calculated as a function of viewing distance. In this thesis, the image SF was manipulated to produce face stimuli of low-SF and high-SF information, and the retina SF was determined by controlling the image size and viewing distance.

2.2.3 SF analysis in the visual system

SF analysis is originally an outcome of mathematics and physics studies, however, as we obtain more depth in human vision, SF analysis of stimulus is no longer a skill of pure mathematics but reflects the processing of visual information by neural mechanisms, which have evolved to facilitate such process (Lamberto Maffei & Fiorentini, 1973; Sachs, Nachmias, & Robson, 1971; Watt, 1987). Studies observed that the visual neurons are selective sensitive to different SFs in the human visual system (Blakemore & Campbell, 1969; Campbell & Maffei, 1970; Maffei & Fiorentini, 1972) and proposed distinct pathways for visual input of low-SF and high-SF (De Valois & De Valois, 1980; Sachs et al., 1971). Low-SF information is preferentially transmitted through the magnocellular pathway, and high-SF information the parvocellular pathway (De Valois & De Valois, 1980; Skottun, 2015; Skottun & Skoyles, 2008a). These pathways connect the optic nerves from the retina to the primary visual cortex (i.e. V1; Livingstone & Hubel, 1988) and transmit the visual signals in different conduction velocities. The magnocellular pathway is formed up by neurons of larger sizes that respond to visual signals in a more transient manner and transmit information more rapidly, whereas the parvocellular pathway is formed by smaller neurons that respond in a more sustained manner and transmit information relatively slower (Shapley & Lennie, 1985; Skottun & Skoyles, 2008a, 2008b).

More recently, distinct cortical processing properties were proposed for information of low-SF and high-SF. Low-SF information travels through both dorsal and ventral stream to reach the medial temporal area (MT) and the V4 respectively; whereas the high-SF information goes through the ventral stream to the V4 area only (Skottun, 2015). Although the two streams have been found to possess distinct processing properties (e.g. processing speed) and contribute differently to visual perception of different stimuli (e.g. level of consciousness; Bullier, 2001; Goodale & Milner, 1992; Lamme & Roelfsema, 2000; Lamme, Supèr, & Spekreijse, 1998; McIntosh & Schenk, 2009; Norman, 2003), it should be noted that these properties have not been directly examined for SF information.

In sum, SF is one of the most important attributes of visual perceptual information that encodes the level of detailed information of a visual display and determines its appearance. For example, low-SF information conveys the coarse large-scale facial configuration and structural changes of a facial expression, and high-SF information depicts the fine details of facial features and abrupt edge changes. Moreover, mechanisms are evolved to facilitate the processing of SF information. This has been found to be advantageous for the computational analysis of visual input (Wilson & Wilkinson, 1997), the outputs of which constitute basic building blocks of information for higher-level recognition or interpretation (Morrison & Schyns, 2001; Skottun, 2015; Thorpe, 2001). It is thus of great interest to know whether we are able to make use of this information to recognise visual stimuli and how it contributes to our understanding of the meanings of the stimuli.

The role of SF information has been studied in the recognition of various types of visual stimuli, including objects (e.g. cup, bird; Biederman & Cooper, 1992; Cheung & Bar, 2014; Craddock, Martinovic, & Müller, 2013; Hagen, Vuong, Scott, Curran, & Tanaka, 2015; Morrison & Schyns, 2001; Parker, Lishman, & Hughes, 1996), scenes (e.g. city, motorway; Issa, Trepel, & Stryker, 2000; Kihara

& Takeda, 2010, 2012; Mu & Li, 2013; Oliva & Schyns, 1997; Parker, Lishman, & Hughes, 1992, 1997; Schyns & Oliva, 1994), and face-related information, such as facial identity (Talis Bachmann, 1991; Bhatia, Lakshminarayanan, Samal, & Welland, 1995; Costen, Parker, & Craw, 1996; Costen, Shepherd, Ellis, & Craw, 1994; Deruelle & Fagot, 2005; Fiorentini, Maffei, & Sandini, 1983; Harmon & Julesz, 1973; Hayes, Morrone, & Burr, 1986; Nasanen, 1999; Ojanpaa & Nasanen, 2003; Parker & Costen, 1999; Sinha, 2002; Tieger & Ganz, 1979), facial gender (Aguado, 2010; Deruelle & Fagot, 2005; Goffaux, 2003; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Schyns & Oliva, 1999), and face configuration (Cheung et al., 2008; Goffaux et al., 2011; Goffaux, Gauthier, & Rossion, 2003; Halit, Haan, Schyns, & Johnson, 2006). However, what is more relevant to the current thesis is the role it plays in the recognition of facial expressions. Therefore, the following sections will focus on the role of SF information in the perception of facial expressions. I will first summarise the hypotheses of SF information processing (section 2.3), and then present evidence for emotion recognition using SF information (section 2.4).

2.3 Hypotheses of SF information processing

There are two main hypotheses regarding the processing of low-SF and high-SF information: The *flexible usage hypothesis* considers the role of SF information in various conditions, and the *coarse-to-fine hypothesis* captures the temporal aspect of SF information processing. These hypotheses were originally generated in a broader context of general visual perception. However, in this section, I will briefly overview the hypotheses with a focus on the perception of emotional facial expressions, which is considered more relevant to the research of this thesis.

2.3.1 Flexible usage hypothesis

The flexible usage hypothesis proposes that when dealing with visual-related tasks with specific requirements, the SF information is used flexibly depending on the usefulness of the information for the task (Morrison & Schyns, 2001; Oliva & Schyns, 1997; Schyns, 1998; Schyns & Oliva, 1999). For example, by using the same face images as stimuli, the low-SF information was preferentially used by observers when categorising the type of emotional facial expressions, whereas the high-SF information was preferred when categorising the expressiveness of the expressions (Schyns & Oliva, 1999). More recently, the hypothesis has been extended to interpret the flexible usage of SF information for stimuli of different emotional content being processed in the same task. For example, when completing an expression categorization task, low-SF information was found to facilitate the recognition of happy faces and high-SF sad faces (Kumar & Srinivasan, 2011).

2.3.2 Coarse-to-fine hypothesis

The coarse-to-fine hypothesis is about the temporal properties of SF information processing. It proposes that in visual perception, a large-scale, coarse description of a stimulus would be firstly formed up, and then the small-scale, fine details would be integrated into the picture to produce a successful recognition and thorough understanding of the target stimulus (Hegdé, 2008). In terms of SF, low-SF information, which conveys large-scale coarse elements, is assumed to be processed at an earlier stage or faster than high-SF information, which conveys the fine details and abrupt edge changes of the same stimulus (Marr & Hildreth, 1980; Morrison & Schyns, 2001; Parker & Costen, 1999; Watt, 1987). This tentative hypothesis is largely rooted in the physiological findings of the temporal features of the neurones and the neural pathways that are selectively sensitive to low-SF and high-SF information, with low-SF being transmitted more rapidly than high-SF. However, the temporal feature of early stage responses may not necessarily be extended to or retained in the later stage processes of recognition or interpretation of a stimulus (see section 2.4.2 for review).

This thesis will consider these two aspects (i.e. flexibility and temporal properties) of SF information processing in the recognition of pain expressions. For example, regarding the flexible usage hypothesis, it is of great interest to know whether SF information would play different roles in pain recognition compared with emotional expressions, and whether it would vary in different tasks. In respect of the coarse-to-fine hypothesis, the temporal features of pain recognition by using low-SF and high-SF information will also be explored. Please refer to section 2.5 for an overview of research questions and experimental studies.

2.4 The recognition of emotional expressions using SF information

As will become apparent, the primary goal of this thesis will be to investigate how facial expressions of pain are recognised in terms of SF information analysis. Though very few studies have investigated the role of SF information in pain recognition, there has been a number of studies on how SF information processing contributes to the recognition of emotional facial expressions[3], which is highly relevant to our understanding of the recognition of pain expressions. Thus, in this section, I will take a closer look at the research on emotional expressions and present evidence for emotion recognition using SF information, in terms of (1) the role of SF information and (2) the temporal features of processing. This will help guide the rationale for why I wish to consider SF in the processing of pain. As will become apparent, both elements are important in facial expression recognition, yet neither have been considered in the context of pain.

2.4.1 The role of SF information

It is well documented that, in a clear viewing condition with intact (i.e. broad-SF) information available, facial expressions of core emotions could be reliably recognised and differentiated from one another (review: Calvo & Nummenmaa, 2015). Then, it would be of interest to know whether the processing

[3] There is another stream of neuroimaging and electrophysiological studies focusing on the emotional responses to facial expressions presented by different SF information (e.g. Bannerman, Hibbard, Chalmers, & Sahraie, 2012; Holmes, Green, & Vuilleumier, 2005; Maratos, Mogg, Bradley, Rippon, & Senior, 2009; Méndez-Bértolo et al., 2016; Pourtois, Elise, Grandjean, Sander, & Vuilleumier, 2005; Vlamings et al., 2009; Vuilleumier, Armony, et al., 2003; Winston et al., 2003). Whilst informative, these studies investigated a different aspect of SF information processing and are not directly relevant to the current thesis. In these studies, participants were not instructed to process the emotional content of the facial expressions, but irrelevant tasks completed (e.g. recognition of face gender, detection of shoes). It is known that our brain responded differently towards the same face stimuli in different tasks that require focal attention on different features of the face to solve the task (Eimer, Holmes, & McGlone, 2003). Therefore, these neural responses to the low-SF and high-SF information do not necessarily contribute to the recognition or categorization of emotional facial expressions, but are automatically elicited by the affective value/emotional quality (Eimer & Holmes, 2007) that could also be elicited by affective objects and scenes (e.g. Alorda et al., 2007; Carretié, Hinojosa, López-Martín, & Tapia, 2007; Delplanque, Diaye, Scherer, & Grandjean, 2007). Thus, these literatures are not thoroughly reviewed here.

of emotional expressions is dependent upon both low-SF and high-SF information and whether the low-SF and high-SF information is of similar importance in this process. A series of studies have been conducted to study the role of SF information in the recognition of different emotions. In these studies, observers were explicitly instructed to process the emotional content of facial expressions, and the role of SF information was examined in terms of their recognition performance. The flexible role of SF information has been found in the perception of different emotional expressions.

For example, Kumar and Srinivasan (2011) found that the recognition of *happiness* mainly relies on low-SF information, whereas the recognition of *sadness* mainly relies on high-SF information. This finding is supported by two additional studies for happiness (Morawetz, Baudewig, Treue, & Dechent, 2011) and sadness (Goren & Hugh, 2006), respectively. Morawetz et al. (2011) found more accurate happiness judgments when using low-SF information compared to high-SF, and Goren and Wilson (2006) found that it is easier (i.e. more accurate) to discriminate sadness using mid-range or high-SF information than low-SF information. For expressions of *anger*, low-SF and high-SF information was found to be equally informative in terms of recognition accuracy (Aguado et al., 2010; Goren & Wilson, 2006).

For *fear* expressions, higher recognition accuracy was found when using low-SF information compared to high-SF (Morawetz et al., 2011; Vlamings, Goffaux, & Kemner, 2009). This is in line with neuroimaging findings that fear expressions presented by low-SF information elicited more pronounced brain (e.g. amygdala) activities compared to those presented by high-SF (Maratos, Mogg, Bradley, Rippon, & Senior, 2009; Méndez-Bértolo et al., 2016; Vuilleumier, Jorge, Driver, & Raymond, 2003; Winston, Vuilleumier, & Dolan, 2003) – though in these neuroimaging studies observers were not instructed to process the emotional content of the expressions explicitly, but irrelevant tasks completed. These findings imply that low-SF information may play a prominent role for fear expressions.

According to these studies, the role of SF information in expression recognition does seem to vary depending on the emotional content of expressions.

However, it should be noted that the expressions mentioned above were examined in separate studies using slightly different tasks, and some other core expressions (e.g. disgust, surprise) have not been studied. Thus, a study that systematically examines the role of low-SF and high-SF information across all the core expressions has not yet been conducted and is needed. Furthermore, few if any studies, have considered this issue within the context of pain expressions.

2.4.2 The temporal features of SF processing

The second general issues to emerge from SF work is to consider the time course of processing. The main approach that has been used to study the temporal feature of SF information processing in emotion recognition is to examine observers' response time (RT). A low-SF advantage has been observed for emotion recognition in multiple studies, where faster responses were made towards expressions presented by low-SF information than high-SF information (Becker et al., 2012; Kumar & Srinivasan, 2011; Morawetz et al., 2011; Vlamings et al., 2009). However, one study reported the opposite that the high-SF expressions were recognised faster than the low-SF expressions (Aguado et al., 2010).

There are several possible reasons for this inconsistency, such as variation in task parameters and expression types. One particular task parameter varied in these studies is the presentation duration of face stimuli. In the above-mentioned studies, where faster responses were found for expressions presented by low-SF information, the face stimuli were presented for a short period of time (e.g. 300 ms); whereas in the study found faster responses to expressions presented by high-SF information, a much longer presentation duration was used (e.g. 2000 ms).

Presentation duration is an important task parameter that is relevant to the temporal aspect of information processing for visual stimuli (Bachmann, 1987). Though the effect of presentation duration on SF information processing has not been directly examined for emotion recognition, in the perception of natural scenes, the *usage preference* of SF information is modified by the presentation duration of stimuli – the scene perception was dominated by low-SF information when the presentation duration was brief (i.e. 30 ms) and high-SF information when the scenes were presented for a longer duration (i.e. 150 ms; Schyns & Oliva, 1994). Moreover, in terms of the preference of SF information, the presentation duration seems also to play a role in the categorization of emotional expressions. In Schyns and Oliva's study (1999), where the face stimuli were presented briefly (50 ms), observers showed a low-SF preference for emotion categorization. Contrarily, in other studies, when longer presentation durations were used (400–1000 ms), low-SF and high-SF information were equally used by observers (Deruelle & Fagot, 2005; Deruelle, Rondan, Collemiche, Rosset, & Da Fonséca, 2008).

These findings seem to indicate that when the presentation duration was brief, low-SF information might play a more advantageous role over high-SF, however, as the presentation duration increased, the low-SF advantage might be eliminated or even overtaken by high-SF. If true, this reveals an important temporal feature of SF information processing and is in line with the coarse-to-fine hypothesis that coarse low-SF information is processed in a more efficient manner and requires less exposure time compared to fine-detailed high-SF information. However, the role of presentation duration has never been directly examined in expression recognition from SF information. Studies are needed to systematically investigate the temporal properties of SF information processing as a function of presentation duration or exposure time. This aspect will be incorporated into my investigation into pain.

2.5 Summary and rationale for this PhD thesis

Taking together, studies on emotional facial expressions have shown that emotion recognition is dependent upon both low-SF and high-SF information, and the role of SF information varies depending on the emotional content conveyed by facial expressions. However, it remains unknown whether SF information would also affect the recognition of *pain* expressions and whether this would be similar to or different from emotional expressions. In terms of the temporal features of SF information processing, the presentation duration of face stimuli seems to play an important role in visual perception. If so, then we could also ask whether presentation duration affects the processing of SF information in the recognition of pain expressions, and will pain expressions be processed more efficiently compared to emotional expressions? To answer these questions, a series of experimental studies were conducted in this thesis to investigate whether and how pain expressions could be recognised using SF information and compared with emotional expressions.

As outlined in Chapter 1, there may be possible sex differences in pain communication, and so worth examining the role of the observer's sex in the recognition of facial expressions of pain using SF information. Although few types of research have examined sex differences in the processing of SF information (Laeng, Profeti, Saether, et al., 2010), there is evidence for sex-related effects in the decoding of facial expressions of pain (Hill & Craig, 2004; Keogh, 2014; Keogh & Holdcroft, 2002; Prkachin, Mass, & Mercer, 2004). For example, females showed higher sensitivity to the intensity of pain expressions than males (Hill & Craig, 2004; Prkachin, Mass, & Mercer, 2004). However, it remains unknown whether sex differences exist in the recognition of pain expressions. Since females have been found to be generally better at recognising emotional expressions than males (Hall, 1978, 1990; Hall & Matsumoto, 2004; Hall, Hutton, & Morgan, 2010; Hampson, Vananders, & Mullin, 2006; Kret & De Gelder, 2012; Montagne et al., 2005; Thayer & Johnsen, 2000), the question to ask is whether females would outperform males in the recogntion of pain expressions as well? Additionally, we could ask whether males and females perceptually process pain expressions differently in terms of SF information analysis. To answer these questions, the role of the observer's sex was examined in the experimental studies within this thesis.

2.6 An overview of research questions and experiments in this thesis

2.6.1 Research questions

This thesis aims to investigate how facial expressions are processed by observers to make the recognition of pain possible. By taking a perceptual perspective, this thesis views facial expressions as a type of visual stimulus and examines the recognition of facial expressions of pain in terms of the processing of a type of fundamental perceptual information – SF information. To understand how pain expressions are recognised in terms of SF analysis, a series of experimental studies were conducted to primarily explore: (1) the role of SF information in the recognition of pain (i.e. what information is important for pain recognition?), and (2) the temporal features of SF information processing for pain recognition (i.e. how is it processed?). Alongside the primary questions, the secondary aims are to explore (1) whether pain expressions are processed in a similar way to core emotions, and (2) whether men and women recognise pain differently by using SF information. In order to answer these research questions, a series of experiments were conducted and are presented in this thesis. The research questions are summarised and presented in Table 2-1 for each experiment.

Table 2-1 Summary of research questions of each experiment in this thesis.

	Experiment (Chapter)	Primary research questions	Secondary research questions	
The role of SF information	Experiment 1 (Chapter 4)	What role does low-SF and high-SF information play in the recognition of pain expressions?	Are pain expressions processed in a similar way to core emotions?	Does observers' sex play a role?
	Experiment 2–4 (Chapter 5)	Is low-SF or high-SF information more salient for the perception of pain expressions? Is this modified by the presentation duration of face stimuli?		
Temporal feature of SF processing	Experiment 5 (Chapter 6)	Is the role of low-SF and high-SF information in the recognition of pain expressions modified by the presentation duration of face stimuli?		
	Experiment 6 (Chapter 7)	How fast is the processing of low-SF and high-SF information in the recognition of pain expressions?		
	Experiment 7 (Chapter 8)	How fast is the extraction and decoding process of low-SF and high-SF information in the recognition of pain expressions?		

* Broad-SF information (i.e. intact image) was included in all the experiments for comparison;

** The secondary research questions were examined in each of the experiments.

2.6.2 Experimental work: an overview[4]

Stimuli preparation and manipulation (Chapter 3)

To study the recognition of pain using SF information and compare with core emotions, a stimulus set of facial expressions presented by different SF information was generated. This chapter describes how the stimulus set was selected, validated, and manipulated for use in this thesis.

Experiment 1: The role of SF information in pain recognition (Chapter 4)

This experiment investigated the contribution of low-SF and high-SF information to the recognition of facial expressions of pain. Two different tasks were employed – a multiple expression identification task and a dual expression discrimination task – to examine the role of SF information under different task parameters.

Experiment 2–4: Perceptual preference of SF information for pain expressions and the effect of presentation duration (Chapter 5)

Three independent hybrid experiments were conducted to examine whether low-SF or high-SF information is more salient for pain expressions. In these experiments, hybrid faces were used to create conflict situations by merging one low-SF and one high-SF face, each showing a different expression. The perceptual preference was examined in terms of participants' response bias. In each experiment, multiple presentation durations were used to investigate the temporal feature of SF processing.

Experiment 5: The temporal feature of pain recognition using SF information – the effect of presentation duration (Chapter 6)

This experiment investigated the role of low-SF and high-SF information in the recognition of facial expressions of pain as a function of presentation duration. The face stimuli were presented for multiple presentation durations to

[4] Each of the *experiments* was completed by an independent group of participants. If there were multiple *tasks* within one experiment, the tasks would be completed by the same group of participants for that experiment.

investigate the temporal feature of SF information processing in a categorization task.

Experiment 6: The time course of recognising backward masked pain expressions using SF information (Chapter 7)

This experiment investigated the role of low-SF and high-SF information in the recognition of backward masked pain expressions and the time course of SF information processing. A backward masking paradigm was used to disrupt the processing of a target facial expression by a mask at various time points and examine the corresponding visual percept of the expression using different types of SF information in a categorization task.

Experiment 7: The temporal dynamics of SF information processing at different stages of pain recognition (Chapter 8)

This experiment examined the temporal dynamics of low-SF and high-SF information at different processing stages in the recognition of pain expressions. Two modified backward masking tasks were conducted.

Chapter 3 Stimuli preparation and manipulation[5]

To study the effect of SF information on the recognition of pain expressions, a stimuli set was generated for experiments. This chapter describes the stimuli selection, preparation, and manipulation procedure.

3.1 Stimuli selection

Prior to the main experimental studies, a stimuli set of facial expressions that varies SF information was generated. Rather than creating a new stimuli set by myself, an existing set of facial expressions including pain, neutral and core emotions was selected. The selection process and the construction of stimuli set are described in the following sections.

3.1.1 Posed vs. genuine expressions

Posed facial expressions of pain and core emotions were chosen to use in this thesis. Whilst there are known differences between posed and genuine expressions (Bartlett et al., 2014; Hill & Craig, 2002; Larochette et al., 2006; Poole & Craig, 1992), an extensive literature have argued and demonstrated that the use of posed expressions is common and acceptable in expression recognition research (reviews: Adolphs, 2002; Calvo & Nummenmaa, 2015).

It was decided that the posed expressions used in the current experimental studies were to be taken from previously validated image sets. Images needed to be produced by trained professionals based on FACS and carefully validated. These expressions should be highly recognisable and distinct from one another in multiple studies. For example, recognition accuracies of posed pain (Kappesser & Williams, 2002; Simon et al., 2008) and core emotions (Calder et al., 2000; Calvo & Lundqvist, 2008; Calvo & Nummenmaa, 2009; Elfenbein & Ambady, 2003; Palermo & Coltheart, 2004; Recio et al., 2013; Tottenham et al., 2009) were well

[5] The work in this chapter has been included in a peer reviewed journal article that published in PAIN (Wang, Eccleston, & Keogh, 2015).

above chance level and also above 50% when a wide range of expressions were examined (e.g. more than six categories).

Moreover, a general pattern has been found across different posed expression databases, in that the recognition of happiness is typically the most accurate and fastest, followed by surprise, and then anger and sadness, with the lowest accuracy for fear, disgust, and pain (Ekman & Friesen, 1976; Lundqvist, Flykt, & Ohman, 1998; Simon et al., 2008; Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002). These findings suggest that the use of posed expression stimuli is well established, and indeed the vast majority of emotion recognition research rely on well controlled, validated posed expressions.

By using stimuli of posed expressions, this thesis examines the recognition of prototypical facial expressions of pain. However, it must be noted that the posed and genuine expressions do vary, such as (1) posed expressions are designated to depict unitary emotions, whereas, in real life, spontaneous, genuine expressions often encode blended feelings (e.g. pain experience is often accompanied by fear); and (2) posed expressions often show full-blown expressions at high expressiveness, while real life expressions could sometimes be subtle. I should be mindful of this when drawing a conclusion and will return to this point in the general discussion (Chapter 9).

3.1.2 Selection of the stimuli set

There are a number of possible stimuli sets available that include pain, such as the Keltner's database (Keltner, 1996), the STOIC database (Roy et al., 2007), the Montreal pain and affective face clips (Simon et al., 2008), and the UNBC-McMaster shoulder pain expression archive (Lucy, Cohn, Prkachin, Solomon, & Matthrews, 2011), which have been frequently used in published studies. The stimuli set used in this thesis was selected based on a series of criteria listed in Table 3-1.

Table 3-1 Checklist of facial expression databases that include pain expressions.

Database	Keltner's database	STOIC	Montreal face clips	The UNBC-McMaster archive
Pain expression included	√	√	√	√
Six core emotions included	√	√	√	
Neutral expression included		√	√	
Prototypical expressions	√	√	√	
Position controlled		√	√	
Expressiveness controlled		√	√	
Hair and body feature controlled		√		
Validated	√	√	√	√
Number of models	4	10	8	129
Balanced gender of models	√	√	√	
Greyscale image	√	√		
Standardised image size		√	√	√
Standardised image luminance		√		
Used in published research	√	√	√	√

As shown in Table 3-1, the Keltner's database and the UNBC-McMaster shoulder pain expression archive were not chosen mainly because of the lack of neutral and emotional expressions, respectively. Both the STOIC database and the Montreal pain and affective face clips include pain, neutral, and six core emotions, and are carefully controlled over, e.g. expressiveness. The STOIC database of facial expressions was finally chosen for this thesis because the images are standardised and calibrated in terms of size, colour and luminance level, which is beneficial for studying the visual processing of SF information (De Valois & De Valois, 1980). In addition, the stimuli in the STOIC database are elliptical masked to exclude non-facial cues, whereas, in the Montreal database, head and shoulder movements are included, which may add expressive bodily cues to the stimuli. As we know, body postures could also communicate pain and basic emotions (Walsh et al., 2014). Taking together, the STOIC database was chosen, and the face images were used as original stimuli in this thesis.

3.1.3 *Description of the original stimuli set (STOIC)*

The original STOIC facial expression database included pain, neutral and six core emotions (anger, disgust, fear, happiness, sadness, and surprise), all presented by ten models (five females and five males). All basic stimuli are standardised greyscale images (256×256 pixels) with calibrated luminance level and elliptical masks to exclude non-facial cues. To create the database, Roy and colleagues (2007) collected a total of 7000 video clips from 34 actors, of which 1088 video clips were selected on the basis of observers' ratings (most genuine). From these, a static stimuli set (images) was extracted based on the apex (the most expressive frame) of each video. In their validation studies, observers rated each stimulus for the intensity of pain, anger, disgust, fear, happiness, sadness and surprise. For each expression, the most recognisable videos and images that possessed similar affective intensities were selected. The final STOIC database comprised of 80 videos (mean rating proportions[6] for all expressions > 0.80) and 80 images (mean rating proportions for all expressions > 0.78) from 10 actors (5 females and 5 males), with each actor facially expressing all 8 expressions (i.e. pain, neutral and 6 core emotions).

Although the original STOIC database included both dynamic (videos) and static stimuli (images) of the facial expressions, only the static stimuli were used in this thesis. This was because exposure duration has previously been found to influence the perception of SF information (Bachmann, 1987; Ruiz-Soler & Beltran, 2006). As stimulus exposure time is associated with the video clip duration, using dynamic stimuli (videos) would introduce a more complex array of factors into the experiments, such as the amount of dynamic facial movements and the intensity of facial actions. Therefore, at the very early stage of research on this topic, I would like to firstly examine the role of SF information in the recognition of *static* pain expressions and justify the general methodology and then progress to the investigation of more complex dynamic facial expressions in future research.

[6] The mean rating proportion refers to averagely to what extent the observers perceive the pain expressions as showing pain, for example.

3.2 Further validation of stimuli

While the STOIC database of facial expressions has been validated (Roy et al., 2007) and successfully used in various studies (Blais, Roy, Fiset, Arguin, & Gosselin, 2012; Czekala et al., 2015; Hammal, 2014; Hammal & Kunz, 2012; Hammal & Massot, 2011; Roy et al., 2015; Roy et al., 2008; Roy, Blais, Fiset, & Gosselin, 2010; Willenbockel, Lepore, Nguyen, Bouthillier, & Gosselin, 2012), a validation study was conducted within this thesis to further confirm the validity (recognition accuracy) of the expressions. In addition to this, one of the goals of the thesis was to compare pain expressions against core emotions. Therefore, this validation study also served to gain additional ratings on the valence and arousal, which would be used to select the comparison expressions.

3.2.1 Participants

Ten healthy adult participants (five females and five males) were recruited from the University of Bath. The sample had a mean age of 25.10 (SD = 3.00). All participants had normal or correct to normal vision and reported being pain-free and free from any psychiatric or neurological condition. Participants were not paid for taking part in this validation study. Informed consent was obtained from each participant before taking part in the study. Ethical approval was granted by the Department of Psychology Ethics Committee (Ref. 13-002) and the Department of Health Ethics Committee (Ref. EP 12/13 64) of the University of Bath.

3.2.2 Procedure

The task was designed and controlled using E-Prime professional 2.0. Stimuli were displayed in their original size of 7.62 × 7.62 cm on a 19" LCD screen with the resolution of 1280 × 1024 pixels and a refresh rate of 60 Hz. Participants' viewing distance was approximately 60 cm with a visual angle of 3.63°. Each participant completed 80 trials (1 face image per trial; 8 expressions × 10 models per expression). In each trial, participants were shown a fixation cross at the centre of the screen for 500 ms followed by a face stimulus. Participants were asked to identify the expression of the face from a list of 8 options (*1* = happiness, *2* = sadness, *3* = disgust, *4* = surprise, *5* = pain, *6* = anger, *7* = fear, and *8* = neutral) by pressing the corresponding key on the keyboard (1 to 8, respectively). They then rated the valence and arousal level of the expression on two 7-point scales by pressing the corresponding key labelled on the keyboard: with respect to valence, *-3* = clearly unpleasant to *+3* = clearly pleasant; and arousal, *-3* = highly relaxed to *+3* = highly arousal. The face image remained on the screen in each trial until participants responded. The stimuli were shown in a random order.

3.2.3 Results

3.2.3.1 Stimulus recognisability

The number of hits (correct responses) was calculated for each participant. No outliers were found. Due to the small sample size (n = 10), data distribution was not examined, and non-parametric tests were used for data analysis (Siegel, 1957). One-sample binomial tests revealed that all the expressions were identified at a better than chance level (test proportion = 12.5%; all ps < .001, Cohen's gs > 0.48). To examine this further, a confusion matrix on the number of responses was created (see Table 3-2) to compare the number of responses to target and non-target expressions. For example, for pain stimuli, the proportion of pain responses was 78%, and the sum of responses to anger, disgust, fear, happiness, neutral, sadness and surprise expressions was 22%. One-sample binomial tests revealed that all the target expressions could be unambiguously identified (test proportion = 50%; for anger, $p < .001$, Cohen's $g = 0.35$; disgust, $p < .05$, Cohen's $g = 0.11$; fear, $p < .05$, Cohen's $g = 0.11$; happiness, $p < .001$, Cohen's $g = 0.48$; neutral, $p < .001$, Cohen's $g = 0.29$; pain, $p < .001$, Cohen's $g = 0.28$; sadness, $p < .001$, Cohen's $g = 0.33$; and surprise $p < .001$, Cohen's $g = 0.40$). For completeness and comparison with previously published studies, the simple hit rate and the unbiased hit rate (Wagner, 1993) were also calculated using the following formulas.

$$Simple\ hit\ rate\ = \frac{\textit{Number of hits}}{\textit{Number of expressions presented}};$$

$$Unbiased\ hit\ rate\ = \frac{\textit{(Number of hits)}^2}{\textit{(Number of expressions presented)} \times \textit{(Number of expressions perceived)}}.$$

Table 3-2 Confusion matrix of judgements to the expressions in the validation task.

	Judgements							
Stimuli	Anger	Disgust	Fear	Happiness	Neutral	Pain	Sadness	Surprise
Anger	85	6	2	0	0	4	2	1
Disgust	6	61	1	0	1	17	13	1
Fear	1	3	61	0	1	6	3	25
Happiness	0	0	0	98	0	1	1	0
Neutral	1	0	0	3	79	2	14	1
Pain	1	3	1	9	0	78	5	3
Sadness	0	0	0	1	11	5	83	0
Surprise	1	0	3	0	4	2	0	90

Table 3-3 Mean (*SD*) of simple hit rate, unbiased hit rate, and valence and arousal rating for each expression in the validation task.

	Anger	Disgust	Fear	Happiness	Neutral	Pain	Sadness	Surprise
Simple Hit Rate (%)	85.00	61.00	61.00	98.00	79.00	78.00	83.00	90.00
Unbiased Hit Rate (%)	76.05	50.97	54.72	86.52	65.01	52.90	56.93	65.85
Valence	-1.68 (0.61)	-1.73 (0.44)	-2.04 (0.56)	1.98 (0.59)	0.19 (0.42)	-2.08 (0.70)	-1.64 (0.35)	-0.02 (0.47)
Arousal	1.73 (0.52)	1.45 (0.38)	2.26 (0.54)	-1.48 (0.86)	-0.69 (0.92)	1.90 (0.65)	1.11 (0.48)	1.16 (0.48)

As can be seen in Table 3-3, the accuracy of responses was at an acceptable level across different categories, confirming that the expression sets reflect the intended expressions.

3.2.3.2 Arousal and valence rating for each emotion

In order to determine which core emotional expressions to use as the comparison stimuli, I focused on how similar and/or different the expressions were judged. To achieve this, the valence and arousal ratings for each expression were entered into the following formula (for mean values, see Table 3-3):

$$D = \sqrt{\left(Arousal_{pain} - Arousal_{emotion}\right)^2 + \left(Valence_{pain} - Valence_{emotion}\right)^2};$$

Here *D* is the difference (or distance) between two expressions, and *Arousal* and *Valence* are respectively the mean values of arousal and valence ratings for the expressions. The expression type that was most similar to pain (i.e. least different) was the fear expression (D = 0.36; Figure 3-1). As a comparison, the expression set that showed the greatest difference from pain was also included, which in this case was happiness (D = 5.29; Figure 3-1).

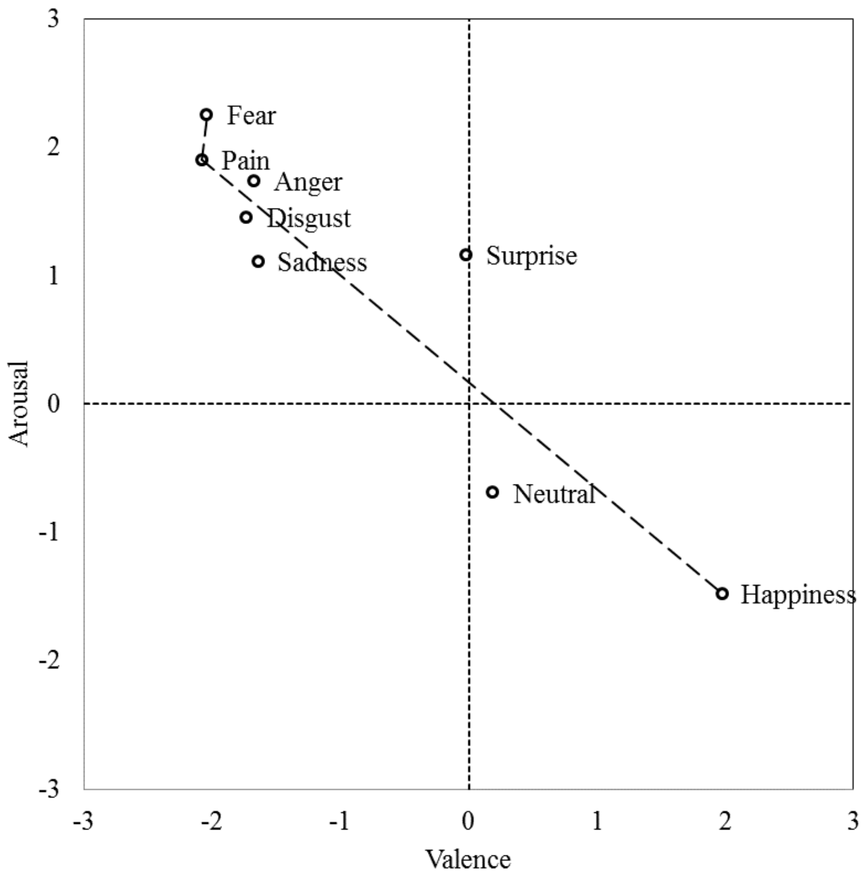

Figure 3-1 Allocation of the expressions in terms of the valence and arousal level.

3.2.4 Discussion

This initial validation study examined the recognisability of the STOIC facial expression images and confirmed that the images reflect the intended expressions and the recognition accuracy was at an acceptable level for all the expressions. The recognition was most accurate for happiness and surprise (>90%), followed by anger, sadness, neutral, and pain (>78%), with the poorest accuracy for fear and disgust (>61%), which is mostly consistent with the pattern of using different facial expression stimuli sets (Calvo & Nummenmaa, 2015; Judith Kappesser & Williams, 2002; Simon et al., 2008).

In addition, this study also determined the comparison expressions that would be used in this thesis. Two emotional expressions were selected regarding the valence and arousal level – one is perceived very similar to pain (i.e. fear), and the other is very different from pain (i.e. happiness). Of note, as the data showed that happiness differed from pain on more than one dimension, selecting happiness as a comparison expression to pain meant that if a difference is found involving happiness expressions, it is not possible to say whether this was due to its valence or arousal. Rather, all that can be concluded is that the happiness expressions were perceived as most different from pain expressions.

3.3 Stimuli manipulation

To investigate the role of low-SF and high-SF information, the SF of the face images was manipulated to separate the low-SF and high-SF information from the original intact stimuli (i.e. broad-SF information). As the SF ranges continuously from low to high, filters with selected cut-off values were created to access certain ranges of SF. For example, a filter that allows all SF lower than a cut-off value to pass through and removes all SF higher than the value is called a low-pass filter. Conversely, a filter that allows all SF higher than a cut-off value to pass through and removes all the lower SF is called a high-pass filter. Therefore, deriving low-SF information could be implemented by applying a low-pass filter with a lower cut-off value; and a high-pass filter with higher cut-off value could be used to gain high-SF information. Selection of cut-off values was consistent with the literature (Becker et al., 2012; Comfort, Wang, Benton, & Zana, 2013; Kumar & Srinivasan, 2011): 8 cycles per face (cpf) was used for the low-pass cut-off, and 32 cpf was used for the high-pass cut-off. More importantly, as introduced in Chapter 2, faces and facial expressions are believed to be processed in a holistic manner, and it has been found that the low-SF and high-SF faces could be processed equally holistically when the cut-off values are 8 and 32 cpf, respectively (Cheung et al., 2008). Thus, these SF cut-off values were used throughout in this thesis.

All images were filtered by low-pass and high-pass Gaussian filters (see Figure 3-2 and 3-3 respectively). The manipulation was completed by MATLAB 2012. First, each original image was Fourier transformed into its frequency domain. Second, low-pass and high-pass Gaussian filters were created with cut-off values of 8 and 32 cpf, respectively. Third, a low-pass or high-pass filter was applied on the Fourier-transformed image. Fourth, the inverse Fourier transform was used to transform the filtered image from its frequency domain to space domain, and the outcome was the filtered image with partial SF information. The low-pass and high-pass Gaussian filters are described as:

$$G_{Low-pass} = \frac{1}{2\pi\sigma^2} \times e^{-\frac{x^2+y^2}{2\sigma^2}};$$

$$G_{High-pass} = \frac{1}{2\pi\sigma^2} \times \left(1 - e^{-\frac{x^2+y^2}{2\sigma^2}}\right).$$

In both of the equations, $e^{-\frac{x^2+y^2}{2\sigma^2}}$ is the 2-demensional Gaussian Kernel function. $\frac{1}{2\pi\sigma^2}$ is a normalisation constant, which ensures the average grey level of the image remains the same after filtering. σ determines the width of the filter, where $\sigma = \frac{\text{the cut-off value}}{\frac{1}{2} \times \text{image size}}$.

After filtering, the averaged luminance level of each filtered image was adjusted to the same level as the original image. This is because the original STOIC images were standardised and calibrated at the luminance level. Each actor (10 in total) displayed each facial expression (8 in total) at each SF level (3 in total). Thus, a total of 240 images were produced, which consisted of 80 broad-SF stimuli (unfiltered), 80 low-SF stimuli (low-passed), and 80 high-SF stimuli (high-passed). For examples of SF-filtered face images, please refer to Figure 3-2 and Figure 3-3.

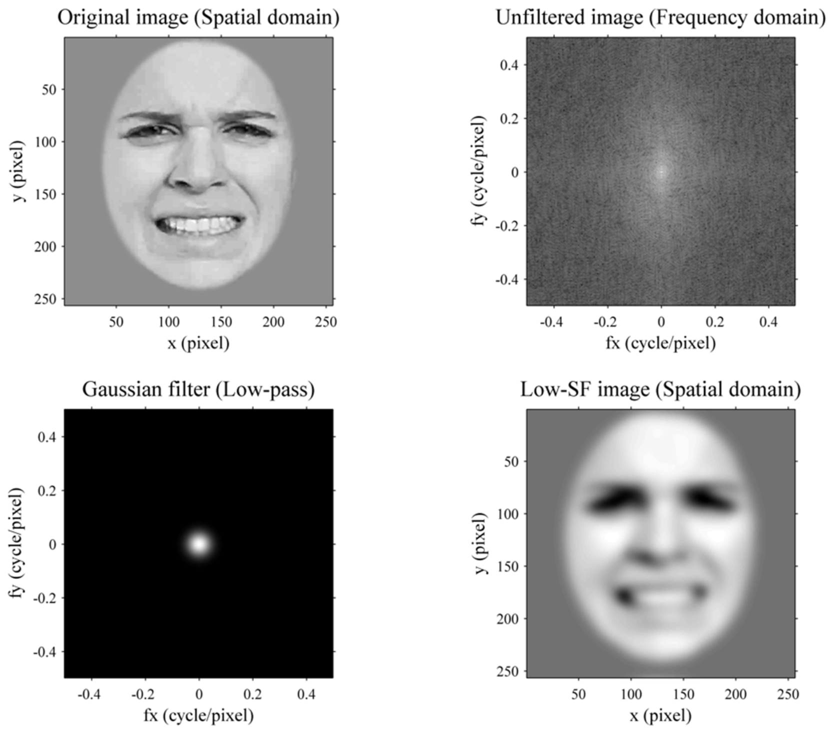

Figure 3-2 Low-SF image filtering procedure.

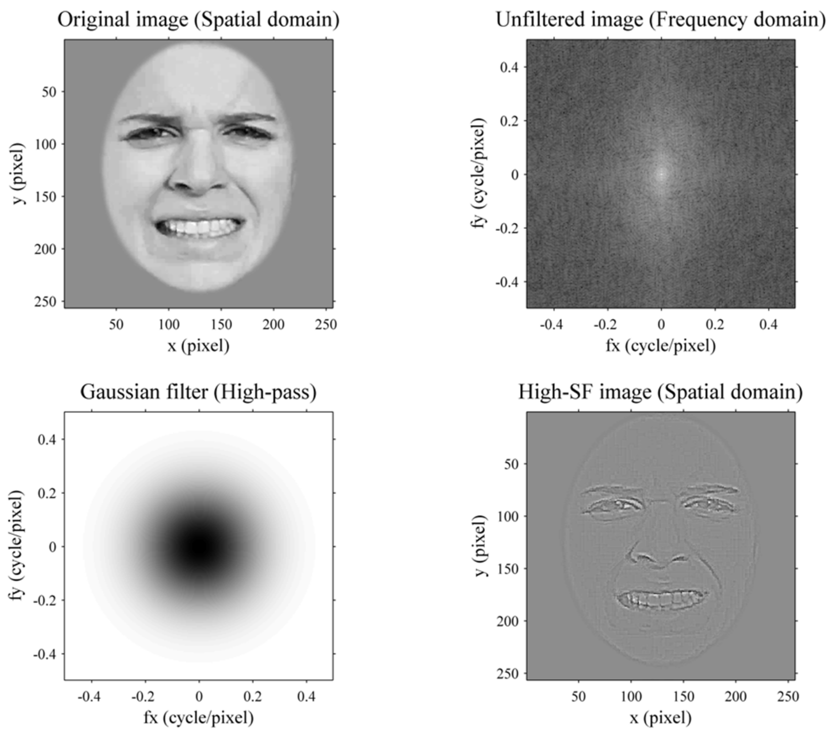

Figure 3-3 High-SF image filtering procedure.

In this thesis, the method of SF filtering was used to manipulate the original face images and produce stimuli contain either low-SF or high-SF information. It should be noted that, in other published studies (e.g. Bombari et al., 2013; White & Li, 2006), additional stimulus manipulation methods have been used, such as pixelization and blurring. In this thesis, the SF filtering was chosen to use, because (1) the SF filtering method does not interrupt the configuration of face stimuli or introduce any new pattern (e.g. pixelisation produces mosaic patterns) that would possibly interact with the processing of face-related information; (2) using SF filtering, the stimuli of low-SF and high-SF could be produced in a unified manner, whereas pixelization and blurring are not able to produce stimuli convey high-SF only; and (3) SF filtering could directly access the stimulus SF in a quantitative manner, but neither pixelisation nor blurring could manage to manipulate the image SF information as precisely as SF filtering.

Chapter 4 Experiment 1: The role of SF information in the recognition of pain expressions[7]

4.1 Introduction

As the first step in the investigation, this experiment aims to examine the role of low-SF and high-SF information in the recognition of facial expressions of pain and compare with core emotions.

As discussed in Chapter 2, previous studies suggest that facial expressions of emotions can be recognised, and judgements made, even when only limited SF information is provided (Aguado et al., 2010; Becker et al., 2012; Comfort et al., 2013; Deruelle & Fagot, 2005; Deruelle et al., 2008; Goren & Wilson, 2006; Kumar & Srinivasan, 2011; Morawetz et al., 2011; Schyns & Oliva, 1999; Vlamings et al., 2009). In addition, the role of SF information in the recognition of emotional expressions has been found to be flexible depending on the emotional content being processed (e.g. Kumar & Srinivasan, 2011). However, it is still unclear whether SF information affects our ability to accurately detect and recognise pain expressions, and in turn whether this is similar or different from expressions of core emotions. This experiment, therefore, examined whether pain faces can be recognised in visually degraded conditions with either low-SF or high-SF information available. The intact broad-SF faces were also included for comparison. I hypothesised that pain would be recognised in faces even when limited SF information is available, and such recognition is at a similar level to core emotions.

As task parameters can also affect expression recognition from SF information (Schyns & Oliva, 1999), this experiment employed two different tasks: a multiple expression identification task, and a dual expression discrimination task. These two tasks are assumed to reflect two different levels of perceptual analysis

[7] A version of this chapter was published as "The role of spatial frequency information in the recognition of facial expressions of pain" in PAIN (Wang et al., 2015).

(Sekuler, 1994). Discrimination allows us to distinguish one category from another by searching for at least one distinctive difference between the two expressions. However, such strategy would not necessarily lead to success in the multiple expression identification task, which requires additional steps and arguably a higher level of specificity to accurately identify the expression. Therefore, in this experiment, it is assumed that different strategies and information analysis would be involved in these two tasks. As the multiple identification is a more complex task, I assumed that more information is required and so predicted that pain recognition would be more impaired by reducing SF information in the identification task compared to the discrimination task.

4.2 Methods

4.2.1 Design

Participants completed an identification task and a discrimination task, both of which employed a mixed-groups design. The within-groups variables were the type of SF information available (broad-SF vs. low-SF vs. high-SF) and expression type (which varied according to the task, see below). A between-groups variable was also include and consisted of participant sex (male vs. female). The dependent variables were accuracy and response time (RT), depending on the task under investigation.

4.2.2 Participants

Sixty-four healthy adult participants (33 females and 31 males) were recruited from the University of Bath. The sample had a mean age of 26.48 (*SD* = 5.93). All participants had normal or correct to normal vision and reported being pain-free and free from any psychiatric or neurological conditions. The same exclusion criteria for participant recruitment were applied in all the experiments in this thesis. Ethical approval was granted by the Department of Psychology Ethics Committee (Ref. 13-002) and the Department of Health Ethics Committee (Ref. EP 12/13 64) of the University of Bath. Informed consent was obtained from all participants before taking part in the experiment. Each participant was given £5 in return.

4.2.3 Stimuli

As described in Chapter 3, a total of 240 stimulus images were produced, which consisted of 80 broad-SF images, 80 low-SF images, and 80 high-SF images. The stimuli used in the identification task and the discrimination task were selected from these stimulus images and varied according to task parameters (see below).

4.2.4 Tasks

Both of the tasks were designed and controlled using E-Prime professional 2.0. The apparatus and display settings were the same as in the validation (Chapter 3, section 3.2.2). The tasks were as follows:

4.2.4.1 Multiple expression identification task

An expression identification task was used to examine whether pain could be identified from faces by using either low-SF or high-SF information. The set of core emotions (i.e. anger, disgust, fear, happiness, sadness, and surprise) and a neutral facial expression were included for comparison. A total of 240 stimuli were used, including facial expressions of pain, neutral, and six core emotions (i.e. anger, disgust, fear, happiness, sad, and surprise), each presented by 10 models at 3 SF levels (i.e. broad-SF, low-SF, and high-SF). Each participant completed 240 trials with a break after every 60 trials.

In each trial, participants were shown a fixation cross at the centre of the screen for 500 ms followed by a face stimulus. The face stimulus was presented one at a time, each for a fixed presentation time of 300 ms. Under natural viewing conditions, on average, humans move their eyes every 300 ms to extract enough visual information for further processing (Henderson & Hollingworth, 1998); thus 300 ms is roughly comparable to a single fixation episode in natural viewing conditions (DiCarlo & Maunsell, 2000). Each of the stimuli was randomly jittered over ± 0.3° to prevent participants from fixating on a particular feature. Following each face stimulus, a list of eight options of expressions (*1 = happiness, 2 = sadness, 3 = disgust, 4 = surprise, 5 = pain, 6 = anger, 7 = fear,* and *8 = neutral*) was shown. Participants were required to choose the expression of the face by pressing the corresponding key (*1* to *8*) on the keyboard. The options of expressions remained on the screen until participants made a response. After obtaining a response, a blank page was presented for 500 ms to reduce the adaptation effect on the retina; then the next trial began with the fixation cross. The stimuli were shown in a random order.

Recognition accuracy served as the key outcome variable on this task. As there were eight possible responses, which could increase the manual response latency and its variance, RT was not examined. As the task was not time dependent, and instructions were displayed in each trial, a practice session was not included.

4.2.4.2 Dual expression discrimination task

This task considered whether participants could distinguish a facial expression of pain from a core emotion by using either low-SF or high-SF information. This is an "either-or" task that requires participants to discriminate whether a given face was showing expression A or expression B. I investigated this in two versions of the task: one was between pain and a core emotion perceived similar to pain (i.e. fear), and the other was between pain and a core emotion perceived different to pain (i.e. happiness). The choice of comparison expressions was determined by responses gained in the validation (Chapter 3 section 3.2.3.2).

The stimuli in this task comprised broad-SF, low-SF, and high-SF images of pain, fear, and happiness expressions. There were 30 images for each expression (i.e. 10 actors displaying each expression at three SF levels: broad-SF, low-SF and high-SF). This task consisted of three different discrimination conditions: pain-fear (similar condition), pain-happiness (different condition), and fear-happiness (counterbalanced section). Each condition was presented as a blocked set of trials, with each comprising 240 trials (each image appeared four times).

In each trial, a fixation cross was presented for 500 ms at the centre of the screen followed by a face stimulus. The face stimulus was presented for 300 ms and randomly jittered over ±0.3° to prevent participants from fixating on a particular feature. Participants were asked to discriminate between two different expressions by pressing the corresponding button on a serial response box (SRBox) as accurately and as quickly as possible. For example, in the pain-happiness condition, participants indicated whether the facial expression shown was pain or happiness. A response could be made within 2000 ms of the onset of the stimulus, after which the trial terminated and moved onto the next trial (i.e. with or without response). A 2000 ms limit is recommended for experiments of this type as a reasonable cut-off to minimise the effect of RT outliers (Ratcliff, 1993). It is also considered long enough to allow participants to make manual responses after conscious processing of a visual stimulus (Liu, Harris, & Kanwisher, 2002; Thorpe, Fize, & Marlot, 1996; Thorpe, 2001). Once a response had been made, a blank screen was displayed for 500 ms to reduce any adaptation effect.

The stimuli in each condition were presented randomly, and the order of conditions was counterbalanced across participants. Each participant was required to complete the three conditions with a break scheduled between each one. A practice session of 10 trials consisting of anger and surprise expressions preceded the main experimental conditions.

4.2.5 Procedure

All participants were asked to complete the identification task first, followed by the discrimination task. This fixed order was chosen over counterbalancing to avoid any potential priming effect from a subset of the stimuli.

4.2.6 Data analysis

For the identification task, the dependent variable was accuracy (number of hits). Data were entered into a 3 × 8 × 2 (SF Information [broad-SF, low-SF, high-SF] × Expression [anger, disgust, fear, happiness, neutral, pain, sad, surprise] × Participant Sex [female, male]) mixed-groups ANOVA. Simple effects analyses were applied when significant interactions found. *Post hoc* analyses with Bonferroni-type correction were conducted when required, and the corrected cut-off point for each analysis was calculated following 0.05/the number of comparison rule (e.g. when there are three comparisons, the corrected cut-off point is 0.05/3 = 0.0167). The significance levels after Bonferroni-type adjustment ($p < .05$, $p < .01$, or $p < .001$) and the effect sizes (Cohen's d) are reported for each comparison. This procedure has been applied repeatedly throughout the analysis.

For the discrimination task, dependent variables were accuracy and RT. Data were analysed separately for each of the three paired conditions. For each paired condition, data were entered into a 3 × 2 × 2 (SF Information [broad-SF, low-SF, high-SF] × Expression [fear vs. pain or happiness vs. pain] × Participant Sex [female, male]) mixed-groups ANOVA. Simple effects analyses were applied when significant interactions found. *Post hoc* analyses followed the same principles as described above for the identification task.

4.3 Results

4.3.1 Identification task

The number of hits (correct responses) was calculated for each participant. No outliers were found for the overall number of hits for each participant, with *z*-scores lying within an acceptable range, i.e. between -3.29 and 3.29 (Tabachnick & Fidell, 2012). The data were normally distributed, with acceptable *z*-scores of skewness and kurtosis between -1.96 and 1.96 (Clark-Carter, 2009), and were approximately homogeneous (all Levene's ps > .05). For factors where sphericity could not be assumed, *F*-ratios with adjusted degrees of freedom and *p*-values are reported below. For completeness and easy comparison across studies, the simple hit rates and unbiased hit rates were calculated and are reported in Table 4-1. One sample binomial tests revealed that expressions were identified above chance level (12.5%) in all conditions by both female and male participants (all ps < .001, Cohen's gs > 0.28).

Mean and *SD* of the number of hits for female and male participants in each condition are presented in Table 4-2.

Table 4-1 The simple hit rate and unbiased hit rate for each expression displayed by broad-SF, low-SF, and high-SF information in the identification task.

		Female (n = 33)			Male (n = 31)		
		Broad-SF	Low-SF	High-SF	Broad-SF	Low-SF	High-SF
Simple Hit Rate (%)	Anger	76.36	65.45	64.24	73.23	68.39	64.52
	Disgust	68.48	66.06	51.82	53.87	46.13	40.65
	Fear	64.24	60.30	57.58	62.90	52.26	54.84
	Happiness	96.06	94.55	94.85	96.45	97.10	95.81
	Neutral	64.85	58.48	68.18	65.16	60.97	64.84
	Pain	71.21	65.76	58.18	66.77	60.97	52.26
	Sadness	80.30	69.39	65.76	73.23	68.71	64.52
	Surprise	80.91	86.97	78.79	78.71	79.35	78.06
Unbiased Hit Rate (%)	Anger	67.05	51.04	47.29	60.89	47.53	40.83
	Disgust	46.20	44.72	33.56	36.28	29.71	24.16
	Fear	47.62	43.01	44.11	43.34	33.20	38.36
	Happiness	87.50	80.38	70.68	89.01	80.07	70.96
	Neutral	51.02	38.92	38.07	48.39	38.80	36.61
	Pain	49.66	46.78	36.87	35.72	33.89	26.29
	Sadness	51.78	42.95	41.60	45.05	43.43	44.65
	Surprise	59.35	58.05	55.22	59.28	54.38	55.40

Table 4-2 Mean (SD) of the number of hits for expressions displayed by broad-SF, low-SF, and high-SF information in the identification task.

	Female (n = 33)			Male (n = 31)		
	Broad-SF	Low-SF	High-SF	Broad-SF	Low-SF	High-SF
Anger	7.64 (1.75)	6.55 (2.02)	6.42 (1.79)	7.32 (2.53)	6.84 (2.22)	6.45 (2.42)
Disgust	6.85 (1.46)	6.61 (1.73)	5.18 (1.93)	5.39 (2.32)	4.61 (2.01)	4.06 (2.38)
Fear	6.42 (1.79)	6.03 (2.11)	5.76 (2.39)	6.29 (2.00)	5.23 (1.93)	5.48 (2.16)
Happiness	9.61 (0.75)	9.45 (0.83)	9.48 (0.97)	9.65 (0.55)	9.71 (0.46)	9.58 (0.67)
Neutral	6.48 (1.37)	5.85 (1.18)	6.82 (1.40)	6.52 (1.39)	6.10 (1.42)	6.48 (1.65)
Pain	7.12 (2.10)	6.58 (2.00)	5.82 (2.08)	6.68 (1.51)	6.10 (2.33)	5.23 (2.45)
Sadness	8.03 (1.07)	6.94 (1.64)	6.58 (1.66)	7.32 (2.29)	6.87 (1.69)	6.45 (1.96)
Surprise	8.09 (1.67)	8.70 (1.16)	7.88 (1.54)	7.87 (2.00)	7.94 (1.44)	7.81 (1.70)

Statistical analysis revealed a significant main effect of SF information, F (2, 124) = 42.64, $p < .001$, $\eta^2_p = .41$. Participants produced more hits on faces with broad-SF information (*mean* = 58.69, *SD* = 6.75) than both low-SF (*mean* = 55.09, *SD* = 6.03; $p < .001$, Cohen's d = 0.56) and high-SF information (*mean* = 52.78, *SD* = 7.32; $p < .001$, Cohen's d = 0.84), and the number of hits was higher when presented with low-SF than high-SF information ($p < .01$, Cohen's d = 0.34).

The main effect of facial expression type was also significant, F (6.03, 374.07) = 56.38, $p < .001$, $\eta^2_p = .48$ (Figure 4-1). The recognition of pain expressions was significantly lower than those found for happiness or surprise faces (both *p*s < .001, Cohen's *d*s > 1.12), but not different from the remaining expressions (all *p*s > .26). In terms of the non-pain comparisons, the most accurately identified expressions were happiness and surprise, which were significantly better than the other expressions (all *p*s < .001, Cohen's *d*s > 0.75), and a greater number of hits were found for happiness compared to surprise (p < .001, Cohen's d = 1.54). In addition, the recognition of anger and sadness was more accurate than those for disgust (both *p*s < .001, Cohen's *d*s > 0.75) and fear (both *p*s < .01, Cohen's *d*s > 0.55). Also, the neutral faces were better recognised than disgust ($p < .01$, Cohen's d = 0.59).

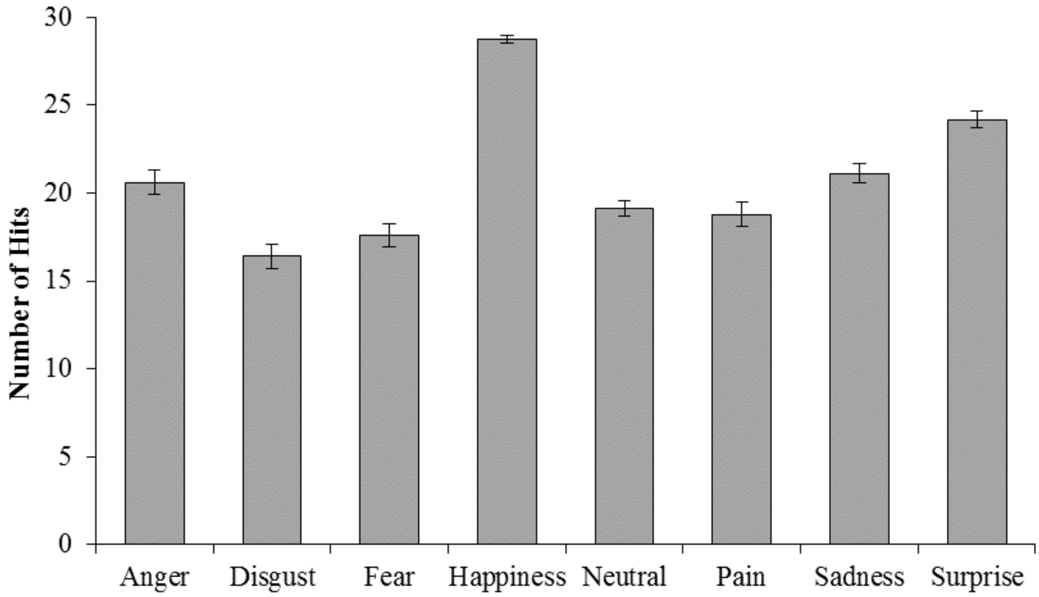

Figure 4-1 Identification accuracy for each facial expression in the identification task (error bars reflect *SEM*).

A significant interaction was found between SF Information × Expression, F (13.22, 819.68) = 7.03, $p < .001$, $\eta^2_p = .10$ (Figure 4-2). Simple effects analysis was applied to examine the effect of SF information on each expression type. The SF information had a significant effect on pain (F (2, 62) = 24.72, $p < .001$, $\eta^2_p = .45$), anger (F (2, 62) = 13.68, $p < .001$, $\eta^2_p = .31$), disgust (F (2, 62) = 16.88, $p < .001$, $\eta^2_p = .36$), fear (F (2, 62) = 5.04, $p < .01$, $\eta^2_p = .14$), neutral (F (2, 62) = 8.34, $p < .001$, $\eta^2_p = .22$), and sadness (F (2, 62) = 18.69, $p < .001$, $\eta^2_p = .38$); but not on happiness (F (2, 62) = 0.43, $p = .65$) or surprise (F (2, 62) = 2.35, $p = .10$). Different patterns emerged based on the type of expression under investigation. For pain and disgust, there were more hits for broad-SF than low-SF (both *p*s < .05, Cohen's *d*s > 0.24) and high-SF information (both *p*s < .001, Cohen's *d*s > 0.67), and better recognition for low-SF compared to high-SF information (both *p*s < .01, Cohen's *d*s > 0.37). For anger, fear, and sadness, recognition was better for broad-SF than low-SF (all *p*s < .05, Cohen's *d*s > 0.35) and high-SF information (all *p*s < .05, Cohen's *d*s > 0.35); however, the difference between low-SF and high-SF information was not significant for these expressions (all *p*s > .21). For neutral faces, the hits for low-SF were less than broad-SF and high-SF information (both *p*s < .01, Cohen's *d*s > 0.40), and there was no significant difference between broad-SF and high-SF information ($p = 1.00$).

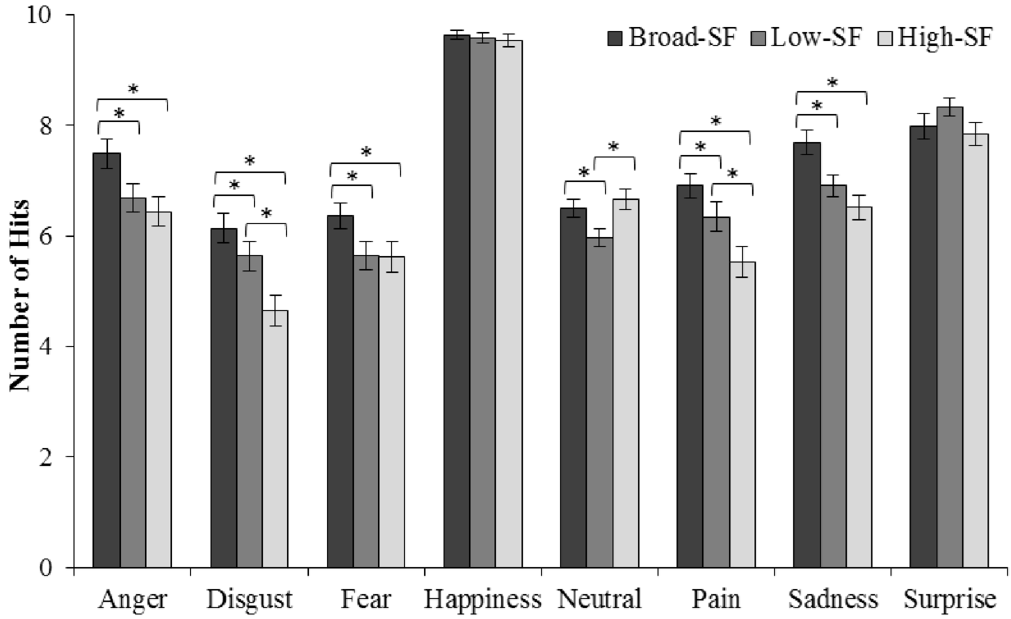

Figure 4-2 Identification accuracy for each facial expression displayed by broad-SF, low-SF, and high-SF information in the identification task (error bars reflect *SEM*; * significant difference).

In terms of sex differences, the main effect of sex was also found to be significant, F (1, 62) = 4.06, $p < .05$, $\eta^2_p = .06$, where females (*mean* = 170.88, *SD* = 17.18) produced more hits than males (*mean* = 161.97, *SD* = 18.20). The interaction between Expression × Sex was also significant, F (6.03, 374.07) = 2.13, $p < .05$, $\eta^2_p = .03$ (Figure 4-3). Simple effects analysis was applied to examine the sex difference within each expression type. The sex difference was only significant in the identification of disgust (F (1, 62) = 13.10, $p < .001$, $\eta^2_p = .17$), where females (*mean* = 18.64, *SD* = 4.17) performed better than males (*mean* = 14.06, *SD* = 5.85). Sex differences in other expressions were not significant, all Fs < 1.22, all ps > .27. The interactions between SF information and participants' sex (F (2, 124) = 0.31, $p = .74$), and SF information, expression, and participants' sex (F (13.22, 819.68) = 1.35, $p = .18$) were not significant. No other significant effects were found.

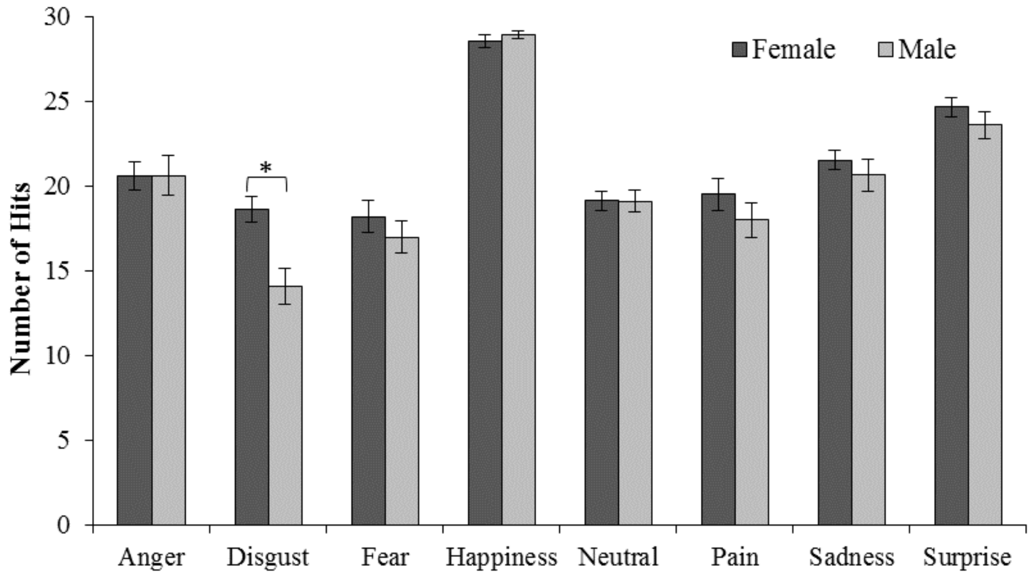

Figure 4-3 Sex differences in the identification accuracy for each facial expression in the identification task (error bars reflect *SEM*; * significant difference).

4.3.2 Discrimination task

Three different analyses were conducted, based on the different expression pairings: pain-fear, pain-happiness, and fear-happiness.

One male participant did not complete this task. Data were screened to remove trials with RTs shorter than 200 ms or longer than 2000 ms (0.4% of all trials). The overall numbers of hit were calculated for each participant in each discrimination condition. One participant (female) was removed due to low response accuracies in both pain-happiness and fear-happiness discrimination, with *z*-scores lower than -3.29. The mean RTs were calculated for each participant under the different levels of the experiment. A second female participant was removed due to long RTs in pain-fear section, with z-scores of the mean RTs exceeding 3.29 in a number of levels. Final data for this task were from a sample of 61 participants (31 females and 30 males). Distributions had an acceptable level of skewness for the number of hits and RTs (Ratcliff, 1993) and were approximately homogeneous (all Levene's *p*s > .05). Simple hit rates and unbiased hit rates were calculated (after screening) and are reported in Table 4-3. One sample binomial tests were applied in all three pairing conditions, which revealed that both expressions in each pairing were recognised above chance level (50%) by both female and male participants (all *p*s < .001, Cohen's *g*s > 0.35).

Table 4-3 The simple hit rate and unbiased hit rate for the discrimination task.

		Female (n = 31)			Male Participants (n = 30)		
		Broad-SF	Low-SF	High-SF	Broad-SF	Low-SF	High-SF
Simple hit rate (%)	Pain	89.77	88.22	89.95	85.77	86.16	85.79
	Fear	89.94	90.45	91.86	88.86	89.52	87.22
	Pain	93.46	91.10	90.54	92.47	90.04	87.20
	Happiness	93.66	92.80	92.14	94.31	92.80	93.22
	Fear	94.58	95.04	94.24	94.48	92.05	92.40
	Happiness	95.68	93.17	92.78	92.06	94.64	92.82
Unbiased hit rate (%)	Pain	80.71	79.66	82.55	75.94	76.78	74.73
	Fear	80.76	79.97	82.73	76.57	77.58	74.93
	Pain	87.48	84.39	83.29	87.12	83.38	80.91
	Happiness	87.58	84.73	83.58	87.34	83.80	81.96
	Fear	90.44	88.65	87.50	87.15	86.99	85.73
	Happiness	90.55	88.47	87.38	86.85	87.30	85.79

4.3.2.1 Pain-fear

Accuracy and RT data were entered, respectively, into two separate 3 × 2 × 2 (SF Information [broad-SF, low-SF, high-SF] × Expressions [pain, fear] × Participant Sex [female, male]) mixed-group ANOVAs. Mean and *SD* can be found in Table 4-4 and 4-5.

Analysis of the accuracy data revealed no significant main or interaction effects, all Fs < 3.02, ps $> .05$.

The RT analysis revealed a significant main effect of expression type, F (1, 59) = 19.00, $p < .001$, $\eta^2_p = .24$. Here, responses to pain faces (*mean* = 695, *SD* = 135) were faster than those found for fear faces (*mean* = 732, *SD* = 135). There was no significant effect of SF information (F (2, 118) = 2.06, $p = .13$) or participant sex (F (1, 59) = 3.36, $p = .07$). None of the interactions was significant (all Fs < 2.06, ps $> .13$).

Table 4-4 Mean (*SD*) of the number of hits for each expression displayed by each type of SF information in the discrimination task.

	Female (*n* = *31*)			Male (*n* = *30*)		
	Broad-SF	Low-SF	High-SF	Broad-SF	Low-SF	High-SF
Pain	35.39 (4.26)	34.94 (4.14)	35.68 (3.52)	33.97 (3.66)	33.83 (4.12)	33.80 (3.95)
Fear	35.58 (4.46)	35.84 (3.77)	36.19 (3.83)	35.10 (4.47)	35.30 (4.29)	34.13 (5.12)
Pain	37.19 (2.66)	36.26 (3.41)	35.87 (3.75)	36.87 (2.57)	35.87 (3.32)	34.73 (4.77)
Happiness	37.29 (2.25)	37.03 (2.35)	36.55 (3.49)	37.57 (1.72)	36.93 (2.27)	37.13 (2.39)
Fear	37.55 (3.21)	37.68 (2.27)	37.32 (2.65)	37.67 (1.95)	36.67 (3.59)	36.87 (3.68)
Happiness	38.03 (1.60)	37.00 (2.39)	36.94 (2.77)	36.70 (3.09)	37.67 (2.32)	37.03 (2.90)

Table 4-5 Mean (*SD*) of the RT for each expression displayed by each type of SF information in the discrimination task.

	Female (*n* = *31*)			Male (*n* = *30*)		
	Broad-SF	Low-SF	High-SF	Broad-SF	Low-SF	High-SF
Pain	654 (117)	661 (102)	667 (106)	717 (155)	740 (163)	734 (162)
Fear	707 (118)	697 (108)	718 (116)	756 (165)	762 (152)	756 (157)
Pain	622 (114)	652 (124)	665 (115)	638 (113)	671 (115)	668 (111)
Happiness	617 (102)	632 (116)	652 (107)	616 (117)	638 (117)	650 (102)
Fear	634 (108)	649 (119)	646 (114)	613 (105)	635 (109)	650 (110)
Happiness	604 (90)	610 (84)	629 (82)	584 (103)	608 (114)	610 (118)

4.3.2.2 Pain-Happiness

A similar analysis was conducted on accuracy and RT data of pain-happiness discrimination, with mean and *SD* presented in Table 4-4 and 4-5.

Statistical analysis of accuracy data revealed a significant main effect of SF information, F (2, 118) = 14.37, $p < .001$, $\eta^2_p = .20$. There were more hits for broad-SF information (*mean* = 74.46, *SD* = 3.26) than for either low-SF (*mean* = 73.05, *SD* = 4.74; $p < .01$, Cohen's $d = 0.35$) or high-SF information (*mean* = 72.15, *SD* = 5.39; $p < .001$, Cohen's $d = 0.52$). However, the difference between low-SF and high-SF information was not significant ($p = .13$). The main effect of expression was significant, F (1, 59) = 4.63, $p < .05$, $\eta^2_p = .07$, with accuracy being better for happiness (*mean* = 111.25, *SD* = 6.33) compared to pain (*mean* = 108.41, *SD* = 9.48).

A significant interaction was found between SF information and expression type, F (1.85, 109.38) = 3.69, $p < .05$, $\eta^2_p = .06$ (Figure 4-4). Simple effects analysis was applied to examine the effect of SF information on each expression. The SF information had significant effects on pain (F (2, 58) = 10.78, $p < .001$, $\eta^2_p = .27$) and happy faces (F (2, 58) = 3.48, $p < .05$, $\eta^2_p = .11$). For pain faces, using broad-SF information was more accurate compared with when using low-SF ($p < .01$, Cohen's $d = 0.32$) or high-SF information ($p < .001$, Cohen's $d = 0.49$); and using low-SF was better than using high-SF information ($p < .05$, Cohen's $d = 0.20$). However, there was no difference in hits for happy faces with broad-, low-, and high-SF information (all *p's* > .08). There were no significant sex differences, F (1, 59) = 0.12, $p = .73$. All other interactions were non-significant (all *F*s < 1.60, *p*s > .21).

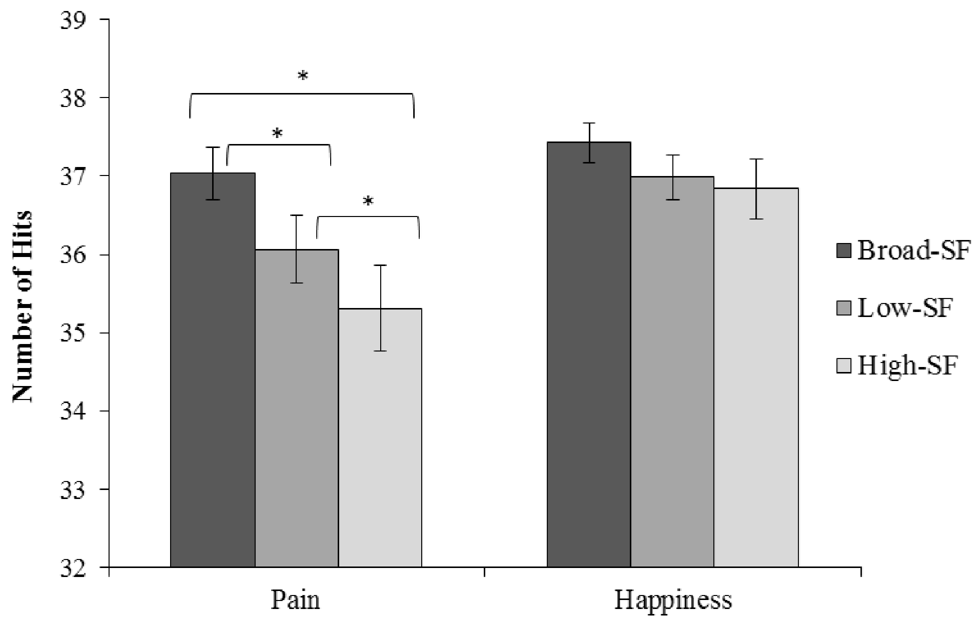

Figure 4-4 Discrimination accuracy for happiness and pain expressions displayed by broad-, low-, and high-SF information in the discrimination task (error bars reflect *SEM*; * significant difference).

The RT analysis revealed a significant main effect of SF information, F (2, 118) = 32.45, $p < .001$, $\eta^2_p = .36$. Performance was faster when presented with broad-SF (*mean* = 623 msec, *SD* = 107) compared with either low-SF (*mean* = 648 msec, *SD* = 114; $p < .001$, Cohen's $d = 0.22$) or high-SF information alone (*mean* = 659 msec, *SD* = 104; $p < .001$, Cohen's $d = 0.34$); but the difference between low-SF and high-SF was not significant ($p = .10$). The main effect of expression was also significant, F (1, 59) = 10.53, $p < .01$, $\eta^2_p = .15$. Happiness (*mean* = 634 msec, *SD* = 106) were identified faster than pain (*mean* = 652 msec, *SD* = 111). There was no significant sex difference (F (1, 59) = 0.06, $p = .81$), and none of the interactions was significant (all Fs < 1.10, all ps > .29).

4.3.2.3 Fear-happiness

Although not the primary focus of this study, for completeness, similar analyses were also conducted on the fear-happiness accuracy and RT data. Mean and *SD* are presented in Table 4-4 and 4-5.

Analysis on the accuracy data revealed significant interaction of SF information, expression, and participant sex, F (2, 118) = 5.12, $p < .01$, $\eta^2_p = .08$. Simple effects analysis was applied to examine the sex differences. The significant sex difference was found in recognising happy faces presented by broad-SF information (F (1, 59) = 4.52, $p < .05$, $\eta^2_p = .07$), in which females produced more hits than males. There was no sex difference in other conditions (all Fs < 1.74, ps > .19). However, none of the main effects or other interactions was significant (all Fs < 1.89, ps > .15).

Statistical analysis on RT data revealed a significant main effect of SF information, F (2, 118) = 19.75, $p < .001$, $\eta^2_p = .25$. Broad-SF faces (*mean* = 609 msec, *SD* = 97) were identified faster than low-SF (*mean* = 625 msec, *SD* = 103; $p < .001$, Cohen's $d = 0.16$) and high-SF faces (*mean* = 634 msec, *SD* = 101; $p < .001$, Cohen's $d = 0.25$), but the difference between low-SF and high-SF information was not significant ($p = .17$). The main effect of expression was significant, F (1, 59) = 30.06, $p < .001$, $\eta^2_p = .34$. Happiness (*mean* = 608 msec, *SD* = 95) was identified faster than fear (*mean* = 638 msec, *SD* = 106). However, there was no significant sex difference (F (1, 59) = 0.22, $p = .64$) or interactions (all Fs < 1.79, ps > .17).

4.4 Discussion

Different types of SF information (low-SF vs. high-SF) affected the recognition of facial expressions of pain. The recognition of pain faces was best when using intact broad-SF information and reduced when only limited SF information (i.e. either low-SF or high-SF) was available. This pattern was also found for most of the core emotional expressions, with two exceptions: happiness and surprise (see below). This general perceptual information effect has previously been reported in emotion recognition (e.g. Kumar & Srinivasan, 2011), although not in pain.

Whilst losing SF information can reduce the recognition accuracy of pain, performance was still above chance level showing that the presence of either low-SF or high-SF information is sufficient to make the recognition of pain expressions possible. In addition, when compared to most emotional expressions used here, the identification accuracy for pain expressions was similar: only happiness and surprise expressions were better recognised (which may be due to differences in valence and arousal; see Figure 3-1 in Chapter 3). Pain may be similar to identify when compared to other negative emotional expressions (Kappesser & Williams, 2002; Simon et al., 2008), in which both low-SF and high-SF information are required to resolve the recognition with a good level of accuracy. Interestingly, reducing the amount of low-SF information available had a more conspicuous influence on the identification of pain (alongside disgust) in comparison with core emotions. Together, these findings not only support the view that the loss of specific types of perceptual information reduces our ability to recognise pain from facial expressions, but they also indicate that pain and the core emotions share similar perceptual requirements.

The influence of SF information on expression recognition was also dependent on the task being performed. This confirms previous reports that task parameters are important when looking at SF effects (Schyns & Oliva, 1999; Smith & Merlusca, 2014). When conducting the identification task of multiple expressions, the identification of pain was reduced by a loss of both types of SF information. However, the effect of losing low-SF information was greater. When asked to discriminate between two contrasting expressions, a more complex pattern was found that depended upon the expression pairs involved. When expression pairs were perceived as being very different (in both arousal and valence) from one another (i.e. pain and happiness), the role of low-SF and high-SF information was similar to that found in the identification task. Removal of either low-SF or high-SF information reduced pain recognition accuracy, with a stronger impact found when low-SF information was removed but had no effect on the accurate recognition of happiness expressions. However, when expression pairs were perceived as similar to each other (i.e. pain and fear), the removal of both types of SF information was less important. One possible explanation for this difference within the discrimination task might be that the distinction of low-SF or high-SF information contained in expressions perceived similar to each other (i.e. pain and fear) is limited or too subtle to make a difference. Even though pain and fear encoded different facial action units (Ekman et al., 2002), they show similar amount of negative affect at similar arousal level, and both states might be experienced, perhaps simultaneously, when in pain (Crombez, Vlaeyen, Heuts, & Lysens, 1999; Kunz et al., 2012).

An additional interesting finding from the pain-fear discrimination task was that even though both expressions were considered similar, faster responses were made to pain faces compared to those expressing fear. This implies that even when perceptual parameters are similar, pain expressions seem to be easier to process and/or stand out as being more distinctive. Reasons why pain judgments were made faster than fear judgments are unclear, but may reflect the fact that pain closely signals physical (sensory) harm and so is prioritised, whereas fear responses may occur to a range of (non-physical) threats also.

A key question addressed here was whether low-SF or high-SF information would play a prominent role in identifying facial expressions of pain. For the identification task, the responses were more accurate when presenting low-SF over high-SF information. This is consistent with views that low-SF, which conveys coarse information may facilitate the global processing of face-related information. However, this study also showed that the low-SF information advantage was only found for one other type of expression, namely disgust, in the identification task. Furthermore, this advantage was only found for pain within the different pair (i.e. pain and happiness) in the discrimination task. Again, this suggests that the relative contribution of low-SF and high-SF information depends on both the type of expression and task parameters. If the low-SF information is predominantly used for recognising pain expressions, this may have a social advantage. A person who is experiencing pain may not always be able to display facial expression to others in a clear way. For example, challenging visual conditions may mean viewing time is brief, faces are obscured, or they are viewed at distance or in the periphery. In such situations, high-SF information is reduced and only information conveyed by low-SF is available; it would, therefore, be adaptive to be able to quickly detect and accurately recognise pain using low-SF information. Neural mechanisms may have also evolved to facilitate this. Indeed, a subcortical visual processing pathway has been proposed to transfer coarsely degraded (low-SF) information to the amygdala (Méndez-Bértolo et al., 2016; Vuilleumier et al., 2003), which has previously been found to play a pivotal role in processing social cues and threatening facial expressions (Sander, Grafman, & Zalla, 2003) and in the judgment of others suffering (Ochsner et al., 2008; Simon et al., 2006; Presseau et al., 2012). However, this is the first time that the role of SF information has been studied in the context of pain identification, the reliability of this low-SF advantage in pain judgements and possible mechanisms underlying this effect are certainly worth considering further in the following experiments.

The current experiment also produced some unexpected effects. For example, losing low-SF or high-SF information seemed to affect recognition accuracy, but this was not found for happiness and surprise, both of which were the best-identified expressions. The advantage of happiness and surprise has been found before – the responses were typically more accurate for happiness and followed by surprise when compared with other expressions (Calvo & Nummenmaa, 2015). Thus, for happiness and surprise, either low-SF or high-SF information may be sufficient for accurate recognition that could be made with intact broad-SF information available.

Equally puzzling was the failure to find sex differences in the effects of SF information on expression recognition. Whilst male-female differences in emotional expression recognition have been previously reported (Hall & Matsumoto, 2004; Montagne, Kessels, Frigerio, Haan, & Perrett, 2005; Rotter & Rotter, 1988; Thayer & Johnsen, 2000), this study did not find consistent evidence for sex differences, which suggests that men and women may not differ in their ability to use SF information to recognise expressions.

Another unexpected finding in this study was that the low-SF advantage over high-SF information for pain and emotional expressions was found for accuracy, but not response times. Others who have reported that different recognition response times for low-SF and high-SF expressions were found are inconsistent (Aguado et al., 2010; Becker et al., 2012; Kumar & Srinivasan, 2011; Morawetz et al., 2011; Vlamings et al., 2009). This inconsistency may again be due to variation in task parameters, e.g. presentation duration, as discussed in Chapter 2 (section 2.4.2). While the effect of presentation duration has not been examined for facial expressions, it has been found that exposure time to face stimuli and image information (in SF) both play a role in face processing (Ruiz-Soler & Beltran, 2006). For example, it has been shown that when the exposure time is increased, correct detection of faces from high-SF information increases, but decreases for low-SF information (Bachmann, 1987; 1991). Thus, the effect of presentation duration on SF information processing is worth to consider in following experiments.

In sum, this experiment demonstrates that pain expressions could be recognised from either low-SF or high-SF information. However, the coarse low-SF information made a more prominent contribution to pain recognition than high-SF information. This finding suggests that the large-scale, structural information conveyed by low-SF may be more characteristic for pain expressions and more relevant to the recognition of pain when compared to the fine-detailed information conveyed by high-SF. It is, therefore, of great interest to know whether the low-SF information is also perceptually preferred by observers when recognising pain, as this is key to an efficient decoding process of pain expressions. If the characteristic information was preferentially used or perceived by observers, the recognition would be expected to achieve higher accuracy with less effort wasted or time consumed. Thus, in the next experiment, I would like to investigate whether observers would be biased towards using low-SF or high-SF information to recognise pain expressions and examine the effect of presentation duration.

Chapter 5 The preference of SF information for pain expressions – Three hybrid experiments

5.1 Introduction

As reported in Chapter 4, Experiment 1 found that although pain faces could be recognised with either low-SF or high-SF information available, low-SF information made a more prominent contribution. This suggests that the information conveyed by low-SF is particularly relevant for pain recognition when compared to high-SF information. An efficient decoding process of pain is thus assumed to be preferentially based on the perception of low-SF information. However, it is not yet clear whether the low-SF or high-SF information would be preferentially used by observers in the recognition of pain. In Experiment 1, low-SF and high-SF faces were presented individually, and presumably, the observers were forced to make use of the best available information to solve the task. Therefore, it is not possible to say whether the low-SF or high-SF information would dominate observers' perception of pain expressions.

To investigate whether low-SF or high-SF information is more salient for detecting pain from facial expressions, this chapter made use of a paradigm that concurrently presents both types of information in a way that allows one to consider information preferences. Hybrid faces are produced by merging one low-SF and one high-SF face, each showing a different expression (Schyns & Oliva, 1999). For example, in Figure 5-1, the hybrid image on the left is composed of a low-SF component showing pain expression, and a high-SF component showing neutral expression; in contrast, the hybrid image on the right is composed of a low-SF neutral and a high-SF pain. The hybrid faces make the direct competition possible by containing two independent expressions in low-SF and high-SF separately at the same time. In a categorization task, the selected expression accordingly probes which information is preferentially perceived. In Figure 5-1, if the image on the left is perceived to show a pain expression, the low-SF information is preferentially perceived; in contrast, for the image on the right, the perception of pain expression would indicate a preference for high-SF information.

Figure 5-1 Examples of hybrid stimuli of low-SF pain & high-SF neutral (left), and low-SF neutral & high-SF pain (right).

Hybrid visual stimuli have been widely used to study the preference of SF information in the perception of objects (Laprevote et al., 2013; Majaj, Pelli, Kurshan, & Palomares, 2002; Otsuka, Ichikawa, Kanazawa, Yamaguchi, & Spehar, 2014), scenes (Brady & Oliva, 2012; Mu & Li, 2013; Oliva & Schyns, 1997; Schyns & Oliva, 1994), and more importantly face-related information (e.g. gender and expression; Deruelle & Fagot, 2005; Deruelle et al., 2008; Laeng et al., 2013; Laeng, Profeti, Sæther, et al., 2010; Langner, Becker, & Rinck, 2012; Laprevote, Oliva, Delerue, Thomas, & Boucart, 2010; Pourtois, Dan, et al., 2005; Prete, Laeng, & Tommasi, 2014; Schyns & Oliva, 1999; Winston et al., 2003).

By using hybrid faces, studies of emotional expressions investigated the saliency of SF information in emotion perception (Deruelle & Fagot, 2005; Deruelle et al., 2008; Langner et al., 2012; Laprevote et al., 2010; Pourtois, Dan, et al., 2005; Schyns & Oliva, 1999; Winston et al., 2003), and intriguing results were found (De Cesarei & Codispoti, 2013). For example, in emotion perception, the prominence of SF information is flexible, depending on the categorization task being performed (Deruelle & Fagot, 2005; Deruelle et al., 2008; Schyns & Oliva, 1999). Schyns and Oliva (1999) found that when observers were asked to determine the expression type (i.e. anger, happiness, and neutral) of hybrid faces, the expressions presented in the low-SF component were preferentially perceived; whereas when they had to determine the expressiveness level of the same hybrid faces, the judgements were more likely to be made based on the high-SF expressions. Although the effect of expression type was not examined in Schyns and Oliva's study (1999), more recent research using the same hybrid face stimuli found a greater low-SF bias for happiness than anger (control group; Laprevote et al., 2010). However, the preference of SF information in the recognition of pain expressions has not been studied yet.

The current chapter[8], therefore, focuses on whether low-SF or high-SF information would dominate the detection of pain expressions from hybrid faces. As Experiment 1 demonstrated a low-SF advantage for pain expressions, it was accordingly hypothesised that low-SF information would also dominate the perception of pain expressions in competitive situations. In other words, based on the hypothesis, we can expect that a hybrid face is more likely to be perceived as showing pain when the pain expression is presented in the low-SF component than in the high-SF component. In order to compare the expression of pain with core emotions, the hybrid combinations of pain-neutral, pain-fear, and pain-happiness were used. The core expressions of fear and happiness were selected in consistence with Experiment 1 (discrimination task), as they are perceived as very similar to and very different from pain, respectively. The neutral expression was also included as a non-expressive pair. Thus, three independent experiments were conducted to study the three hybrid conditions: a non-expressive hybrid pair (i.e. pain-neutral, Experiment 2), a similar pair (i.e. pain-fear, Experiment 3), and a different pair (i.e. pain-happiness, Experiment 4), which also allowed me to examine whether the preference of SF information in pain perception is modified by the emotional content of the paired/competing expression in hybrid faces.

Moreover, in these experiments, the effect of presentation duration was also examined. As discussed in Chapter 2, it has been pointed out in previous research

[8] These experiments did not examine the SF information preference in the categorization of expressiveness level, but the categorization of expression type only. This is because (1) as an extension of Experiment 1, the current chapter is particularly interested in whether the low-SF information would be preferentially perceived by observers to recognise pain expressions; and (2) this PhD thesis focuses on investigating how pain expressions are recognised using SF information, though the expressiveness perception is also very important and certainly worth investigation in future studies.

on scene perception that the preference of SF information is modified by the presentation duration of hybrid scene stimuli – the perception was dominated by low-SF information, when the presentation duration was brief (i.e. 30 ms); when the hybrid scenes were presented for a longer duration (i.e. 150 ms), the perception was dominated by high-SF information (Schyns & Oliva, 1994). Although such perception shifting from low-SF to high-SF has not been directly examined for facial expressions, different patterns of SF information preference for expression categorization were emerged in different studies using different presentation durations. When hybrid faces were presented briefly (e.g. 50 ms), the expressions presented by low-SF information were more likely to be perceived (Schyns & Oliva, 1999); whereas when longer presentation duration (e.g. 400–1000 ms) was used, the low-SF and high-SF expressions (i.e. smiling and grimacing) were equally perceived (Deruelle & Fagot, 2005; Deruelle et al., 2008).

Thus, for emotional expressions, the preference of SF information may also be affected by the presentation duration, e.g. a low-SF bias associated with the brief presentation. In the experiments of the current chapter, multiple presentation durations (i.e. 33, 67, 150 and 300 ms) were used to investigate whether the SF preference for pain expressions is modified by time. Presumably, pain expressions presented by low-SF information would be preferentially perceived from hybrid faces, in particular when the presentation duration was brief, and this low-SF preference would be diminished as the presentation duration increased.

5.2 Experiment 2: Pain-neutral hybrids

The hybrid faces make direct competition possible by containing two independent expressions in low-SF and high-SF at the same time. Therefore, in each of the experiments of this chapter, the facial hybrids consist of two expressions, with one being pain-related and the other a core emotion. In order to compare the decoding of pain with a series of core emotions, the facial expressions of neutral, fear, and happiness were selected to pair with pain in the three experiments respectively. The neutral expression was included as a non-expressive pair, and the core expressions of fear and happiness were selected in accordance with Experiment 1 as they are perceived as very similar to and very different from pain respectively. Thus, three independent experiments were conducted in parallel to study the three hybrid conditions: a non-expressive hybrid pair (i.e. pain-neutral, Experiment 2), a similar pair (i.e. pain-fear, Experiment 3), and a different pair (i.e. pain-happiness, Experiment 4), which also allowed me to examine whether the SF preference for pain expressions is modified by the emotional content of the paired/competing expression in the hybrid faces.

This experiment examined whether pain expressions presented by low-SF or high-SF information would be preferentially perceived when combined with neutral expressions in hybrid faces.

5.2.1 Methods

5.2.1.1 Design

Participants completed an expression categorization task that employed a mixed-groups design. The within-groups variables were presentation duration (33 vs. 67 vs. 150 vs. 300 ms) and expression presented by low-SF information (pain vs. neutral). As there were only two types of hybrid face combination in this experiment (i.e. low-SF pain & high-SF neutral, and low-SF neutral & high-SF pain), the low-SF information of pain and neutral corresponded to the two types of hybrid face, respectively. A between-groups variable of participant sex (male vs. female) was also included. The dependent variable was response bias towards the low-SF expressions.

5.2.1.2 Participants

Forty-three healthy adult participants (23 females and 20 males) were recruited from the University of Bath. The sample had a mean age of 22.07 (*SD* = 6.14). The participation eligibility and exclusion criteria for recruitment were the same as in Experiment 1 (Chapter 4 section 4.2.2). Ethical approval was granted by the Department of Psychology Ethics Committee (Ref. 13-161) and the Department of Health Ethics Committee (Ref. EP 13/14 33a) of the University of Bath for all three experiments. Informed consent was obtained from all participants before participation. Participants, who were first-year psychology students, were awarded one credit unit for participation; and all other participants were given £5 in return.

5.2.1.3 Stimuli

The low-SF and high-SF filtered face images of pain and neutral expressions were used to produce the hybrid face stimuli in this experiment. The SF filtering of original face images was described in Chapter 3 section 3.3. The hybrid faces were produced by merging a low-SF face and a high-SF face, each showing an expression of pain or neutral. Thus, two types of hybrid faces were produced – low-SF pain & high-SF neutral and low-SF neutral & high-SF pain. Please see Figure 5-1 for examples. In each hybrid face, the two expressions were shown by the same actor, in order to eliminate the potential effect of actors' gender or identity on the perception of expressions. As each expression was presented by ten models (five females and five males) in the original stimulus set, a total of 20 hybrid faces were produced and used as stimuli in this experiment (i.e. two hybrid combinations × 10 models). The hybrid stimuli were produced using MATLAB 2013.

5.2.1.4 Task

The task was designed and controlled using E-Prime professional 2.0. The apparatus and display settings were the same as in the previous experiments (for details, see Chapter 3 section 3.2.2). This task consisted of 4 sessions, with each session assigning a presentation duration[9] from a selection of 33, 67, 150, and 300 ms. The presentation durations of 33 and 150 ms were comparable to the presentation durations used by Schyns and Oliva (1994), where the low-SF to high-SF dominance shifting was found for the perception of scenes. The presentation duration of 67 ms was close to that used in another Schyns and Oliva's study (1999), where a low-SF preference was found for expression categorization. The fixed presentation duration (i.e. 300 ms) used in Experiment 1 of this thesis was also included as the longest duration. This is because, under natural viewing conditions,

[9] The values of 33 and 67 ms were used rather than, for example, 30 or 60 ms, is because of the monitor refresh rate, which is 60 Hz and accordingly requires approx. 16.67 ms to complete one refresh. Thus, in order to reduce the error in brief presentation, only the time lengths that are close to the integral multiples of 16.67 ms were used as stimuli presentation durations.

the average eye gaze fixation is approximately 300 ms (for details, see Chapter 4 Section 4.2.4.1). Thus, in this experiment, the presentation durations allowed no more than one fixation on each hybrid stimulus, which ensures that the responded expression was preferentially perceived rather than freely selected between the two (Harris, Hainline, Abramov, Lemerise, & Camenzuli, 1988; Laprevote et al., 2013).

In each session, participants completed 100 trials, with each hybrid stimulus image (20 hybrid stimulus images in total) appearing five times. In each trial, participants were shown a fixation cross at the centre of the screen for 500 ms followed by a hybrid stimulus. The hybrid stimulus was presented one at a time for the given presentation duration of the session and randomly jittered over ±0.3° to prevent participants from fixating on a particular feature. Participants were asked to recognise the expression of the face by pressing the corresponding button on an SRBox as quickly and as accurately as possible. The buttons were labelled with *pain* and *neutral*.

There was not a correct or incorrect answer in this experiment. The responded expression probes which type of SF information was preferentially perceived by participants. For example, when a hybrid stimulus of low-SF pain & high-SF neutral was shown, a response of *pain* demonstrated that the low-SF information was perceived in preference over the high-SF information, in which a neutral expression was shown in this case. A response could be made within 2000 ms of the onset of the stimulus, after which the trial terminated and moved onto the next trial (i.e. with or without response). A blank screen was displayed for 500 ms prior to the next trial to reduce any adaptation effect, and then the next trial began with the fixation cross.

The hybrid stimuli in each session were shown in a random order, and the order of sessions was counterbalanced across participants. Each participant was required to complete the four sessions with a break scheduled between each one. A practice session of 20 trials preceded the main task. The hybrid stimuli in practice session were randomly selected from the 20 hybrid stimulus images for each participant.

5.2.1.5 Data analysis

One-sample binomial tests (test proportion 50%) were firstly applied to examine whether the expression categorization was driven by low-SF or high-SF information. After this, the effects of presentation duration, expression type, and participants' sex on the SF information preference were examined. The dependent variable was response bias towards the expressions presented by low-SF information. Following the method used by Schyns and Oliva's (1999), the score of response bias was calculated by subtracting the number of high-SF responses from low-SF responses. For example, for the hybrid combination of low-SF pain & high-SF neutral, participant *X* responded 36 times that the hybrid face was showing pain (presented by low-SF), and 14 times that the hybrid face was showing neutral (presented by high-SF). Then, participant *X*'s score of response bias for this type of hybrid face is 36 – 14 = 22.

Data of response bias towards low-SF were entered into a 4 × 2 × 2 (Presentation Duration [33, 67, 150, 300 ms] × Low-SF Expression [pain, neutral] × Participant Sex [female, male]) mixed-groups ANOVA. Simple effects analyses were applied when significant interactions found. *Post hoc* analyses followed the same principles as described in Chapter 4.

5.2.2 Results

Data were firstly screened to remove trials with RT shorter than 200 ms or longer than 2000 ms (1.97% of all trials). The score of response bias was calculated for each participant. No outlier was found, with *z*-scores lying within an acceptable range, i.e. between -3.29 and 3.29. The data were approximately normally distributed, with acceptable *z*-scores of skewness and kurtosis between -3.29 and 3.29, and were approximately homogeneous (all Levene's *p*s > .05). For factors where sphericity could not be assumed, *F*-ratios with adjusted degrees of freedom and *p*-values are reported.

It is notable that, in this experiment, participants' RT was recorded for the purpose of data screening only. The RT data were not included in the analysis because the categorization task was designated to examine the response bias, where the extremely small number of responses was expected in some conditions. However, the number of responses (< 20) was not adequate to produce reliable mean RT in these conditions.

One-sample binomial tests (two-tailed; test proportion = 50%) revealed that expressions presented by low-SF information were perceived in preference over those presented by high-SF information in all conditions by both female and male participants. The results are presented in Table 5-1. Mean and *SD* of the score of response bias towards low-SF are presented in Table 5-2.

Table 5-1 Percentage of responses based on low-SF and high-SF information, and the result of the binomial test (two-tailed; test proportion = 50%) for each hybrid face combination in each condition by female and male participants in Experiment 2 (pain-neutral hybrids).

		Low-SF pain & high-SF neutral				Low-SF neutral & high-SF pain			
		Low-SF	High-SF	Exact *p*	Cohen's *g*	Low-SF	High-SF	Exact *p*	Cohen's *g*
Female	33 ms	73%	27%	< .001	0.23	68%	32%	< .001	0.18
(*n* = *23*)	67 ms	70%	30%	< .001	0.20	59%	41%	< .001	0.09
	150 ms	66%	34%	< .001	0.16	54%	46%	.012	0.04
	300 ms	62%	38%	< .001	0.12	59%	41%	< .001	0.09
Male	33 ms	71%	29%	< .001	0.21	81%	19%	< .001	0.31
(*n* = *20*)	67 ms	69%	31%	< .001	0.19	76%	24%	< .001	0.26
	150 ms	67%	33%	< .001	0.17	73%	27%	< .001	0.23
	300 ms	67%	33%	< .001	0.17	75%	25%	< .001	0.25

Table 5-2 Mean (*SD*) of the response bias towards low-SF information in hybrid faces for female and male participants in Experiment 2 (pain-neutral hybrids).

		33 ms	67 ms	150 ms	300 ms
Female	**Low-SF pain** & high-SF neutral	23.13 (19.25)	19.39 (20.55)	15.26 (18.95)	11.35 (17.87)
(*n* = *23*)	**Low-SF neutral** & high-SF pain	17.35 (22.50)	8.91 (24.30)	3.70 (21.21)	8.83 (20.07)
Male	**Low-SF pain** & high-SF neutral	20.25 (26.13)	17.95 (23.75)	16.45 (24.78)	15.90 (24.90)
(*n* = *20*)	**Low-SF neutral** & high-SF pain	29.25 (13.33)	24.65 (19.51)	22.30 (16.61)	24.15 (16.28)

Statistical analysis revealed a significant main effect of presentation duration, F (2.83, 115.93) = 15.49, p < .001, η^2_p = .27. Greater low-SF bias was found for hybrid faces being presented for 33 ms than those presented for 67, 150, and 300 ms (all ps < .05, Cohen's ds > 0.52), but no other difference was significant (all ps > .10). The main effect of expression was not significant, F (1, 41) < 0.01, p = 1.00.

In terms of sex difference, the main effect of participant sex was not significant, F (1, 41) = 2.60, p = .12. However, a significant interaction was found between expression and participant sex (Figure 5-2), F (1, 41) = 5.17, p < .05, η^2_p = .11. Simple effects analysis revealed significant sex difference in bias for low-SF expressions when they were neutral, F (1, 41) = 7.69, p < .01, η^2_p = .16. Compared to females, males showed greater bias to low-SF expressions when they were neutral (Cohen's d = 0.85). This suggests that females were more likely to perceive the complementary part of a high-SF pain than males, though there was still a low-SF bias. The sex difference for low-SF information when expression were pain-related was not significant, F (1, 41) < 0.01, p = .96.

None of the other interactions were significant, all Fs < 2.03, ps > .11.

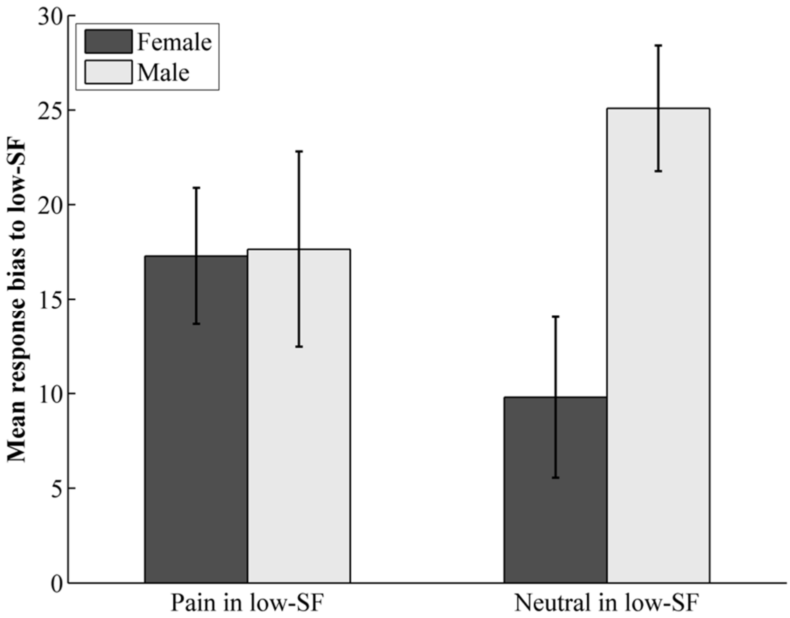

Figure 5-2 Female and male participants' response bias towards low-SF expressions when pain and neutral were presented in the low-SF component in hybrid faces (error bars reflect *SEM*).

Experiment 2 found evidence to suggest that the coarse low-SF information was preferred over the fine-detailed high-SF information for decoding of pain, as well as neutral expressions. This preference was modified by the presentation duration – the bias towards low-SF expressions was largest when hybrid faces presented briefly and reduced as the presentation duration increased. Moreover, there might be a sex difference in the way that high-SF pain information modifies the low-SF biases. Specifically, evidence was found that when the low-SF information was presenting neutral, this bias was reduced when the competing high-SF information was pain-related. However, this pain-related effect was only found in females. It would be interesting to examine whether such effect would also be found when pain expressions are paired with other emotional expressions.

5.3 Experiment 3: Pain-fear hybrids

The second experiment in this series sought to examine whether pain expressions presented in low-SF or high-SF information would be preferentially perceived when combined with fearful expressions in hybrid faces. The expression of fear was chosen as it is perceived similar to pain in terms of the valence and arousal level (see Chapter 3 3.2.3.2 for details).

5.3.1 Methods

5.3.1.1 Design

The same mix-groups design was used as in Experiment 2. The only one difference is that, in the current experiment, the hybrid faces were combined by expressions of pain and fear. In this design, the within-groups variables were presentation duration (33 vs. 67 vs. 150 vs. 300 ms) and low-SF expression (pain vs. fear). The between-groups variable was participant's sex (male vs. female). The dependent variable was response bias towards low-SF expressions.

5.3.1.2 Participants

Another forty-three healthy adult participants (23 females and 20 males) were recruited to complete the current experiment. The sample had a mean age of 25.74 (SD = 5.58). The exclusion criteria for recruitment, the ethical approvals, and the payment information were the same as in Experiment 2.

5.3.1.3 Stimuli

In this experiment, a total of 20 hybrid faces were produced and used as stimuli: two hybrid face combinations of low-SF pain & high-SF fear and low-SF fear & high-SF pain, each being presented by ten models. The hybrid stimuli were produced using the same method as described in Experiment 2.

5.3.1.4 Task

The same expression categorization task was used as in Experiment 2. In this experiment, participants were asked to recognise whether the face stimulus was showing a pain expression or a fear expression.

5.3.1.5 Data analysis

The same data analysis methods were used as in Experiment 2. The only one difference was the expressions used in this experiment was pain and fear. Thus, the data of response bias were entered into a 4 × 2 × 2 (Presentation Duration [33, 67, 150, 300 ms] × Low-SF Expression [pain, fear] × Participant Sex [female, male]) mixed-groups ANOVA.

5.3.2 Results

Data were screened to remove trials with RTs shorter than 200 ms or longer than 2000 ms (2.47% of all trials). The score of response bias was calculated for each participant by subtracting the number of high-SF responses from low-SF responses. No outliers were found. The data were normally distributed and were approximately homogeneous. The same criteria were applied as in Experiment 2. For factors where sphericity could not be assumed, *F*-ratios with adjusted degrees of freedom and *p*-values are reported.

One-sample binomial tests (two-tailed; test proportion = 50%) revealed that expressions presented by low-SF information were perceived in preference to those presented by high-SF information in all conditions. However, there was one exception: for hybrid faces of low-SF fear & high-SF pain being presented for 300 ms, female participants did not show significant low-SF (53%) preference over high-SF (47%), with the exact *p*-value being equal to the significance cut-off value of .05. The results are presented in Table 5-3. Mean and *SD* of the score of response bias for female and male participants in each condition are presented in Table 5-4.

Table 5-3 Percentage of responses based on low-SF and high-SF information, and the result of the binomial test (two-tailed; test proportion = 50%) for each hybrid face combination in each condition by female and male participants in Experiment 3 (pain-fear hybrids).

		Low-SF pain & high-SF fear				Low-SF fear & high-SF pain			
		Low-SF	High-SF	Exact *p*	Cohen's *g*	Low-SF	High-SF	Exact *p*	Cohen's *g*
Female	33 ms	66%	34%	< .001	0.16	63%	37%	< .001	0.13
(*n* = 23)	67 ms	60%	40%	< .001	0.10	60%	40%	< .001	0.10
	150 ms	56%	44%	< .001	0.06	57%	43%	< .001	0.07
	300 ms	59%	41%	< .001	0.09	53%	47%	.050	0.03
Male	33 ms	67%	33%	< .001	0.17	67%	33%	< .001	0.17
(*n* = 20)	67 ms	62%	38%	< .001	0.12	62%	38%	< .001	0.12
	150 ms	62%	38%	< .001	0.12	60%	40%	< .001	0.10
	300 ms	58%	42%	< .001	0.08	59%	41%	< .001	0.09

Table 5-4 Mean (*SD*) of the response bias towards low-SF information in hybrid faces for female and male participants in Experiment 3 (pain-fear hybrids).

		33 ms	67 ms	150 ms	300 ms
Female	**Low-SF pain** & high-SF fear	15.00 (13.75)	9.26 (14.34)	5.74 (13.99)	8.35 (13.91)
(n = 23)	**Low-SF fear** & high-SF pain	12.61 (14.56)	9.91 (15.88)	6.22 (15.34)	2.87 (18.48)
Male	**Low-SF pain** & high-SF fear	16.20 (18.67)	12.00 (19.77)	11.65 (18.26)	7.20 (19.03)
(n = 20)	**Low-SF fear** & high-SF pain	16.80 (22.37)	11.80 (20.20)	9.85 (19.90)	8.55 (25.18)

Statistical analysis revealed a significant main effect of presentation duration, F (3, 123) = 14.86, $p < .001$, $\eta^2_p = .27$. As before, participants exhibited the greatest low-SF bias with presentation time of 33 ms than 67, 150, and 300 ms (all ps < .01, Cohen's ds > 0.53); and greater bias was also found between 67 ms and 300 ms (p < .05, Cohen's d = 0.49).

The main effect of expression was not significant, F (1, 41) = 0.22, p = .64. No significant sex difference was found, F (1, 41) = 0.56, p = .46. None of the interactions was significant, all Fs < 0.86, ps > .46.

Similar to Experiment 2, Experiment 3 found a response bias towards low-SF in the detection of both pain and fearful information from facial expressions, and again the size of the bias was reduced as the presentation duration increased. In particular, women seemed to detect the fine-detailed high-SF pain information as often as the competing low-SF fear when the hybrid faces being presented for a longer duration (i.e. 300 ms). However, this effect was not observed for men.

5.4 Experiment 4: Pain-happiness hybrids

This experiment examined whether pain expressions presented by low-SF or high-SF information would be preferentially perceived when combined with happiness expressions in hybrid faces.

5.4.1 Methods

5.4.1.1 Design

The same mix-groups design was used as in Experiment 2 and 3. The only one difference is that in the current experiment the hybrid faces were combined by expressions of pain and happiness.

5.4.1.2 Participants

An additional forty-three healthy adult participants (23 females and 20 males) were recruited to complete the current experiment. The sample had a mean age of 23.30 (SD = 4.71).

5.4.1.3 Stimuli

In this experiment, a total of 20 hybrid faces were produced and used as stimuli: two hybrid combinations of low-SF pain & high-SF happiness and low-SF happiness & high-SF pain, each being presented by ten models.

5.4.1.4 Task

The same expression categorization task was used as in Experiment 2 and 3. In this experiment, participants were asked to identify whether the face stimulus was showing a pain expression or a happiness expression.

5.4.1.5 Data analysis

The same data analysis methods were used as in the previous two experiments. The only one difference was the hybrid combination used in this experiment was pain and happiness. Thus, the data of response bias were entered into a 4 × 2 × 2 (Presentation Duration [33, 67, 150, 300 ms] × Low-SF expression [pain, happiness] × Participant Sex [female, male]) mixed-groups ANOVA.

5.4.2 Results

One female participant was excluded from further analysis due to lack of responses in multiple conditions. Afterwards, data were screened to remove trials with RTs shorter than 200 ms or longer than 2000 ms (2.35% of all trials). The score of response bias was calculated for each participant. No outliers were found. The data were approximately normally distributed and homogeneous. Final data for this experiment were from a sample of 42 participants (22 females and 20 males). For factors where sphericity could not be assumed, *F*-ratios with adjusted degrees of freedom and *p*-values are reported.

One-sample binomial tests (two-tailed; test proportion = 50%) revealed that expressions presented by low-SF information were perceived in preference to those presented by high-SF information in all conditions by both female and male participants. The results are presented in Table 5-5. Mean and *SD* of the score of response bias towards low-SF expressions in each condition for female and male participants are presented in Table 5-6.

Table 5-5 Percentage of responses based on low-SF and high-SF information, and the result of the binomial test (two-tailed; test proportion = 50%) for each hybrid face combination in each condition by female and male participants in Experiment 4 (pain-happiness hybrids).

		Low-SF pain & high-SF happiness				Low-SF happiness & high-SF pain			
		Low-SF	High-SF	Exact *p*	Cohen's *g*	Low-SF	High-SF	Exact *p*	Cohen's *g*
Female	33 ms	66%	34%	< .001	0.16	82%	18%	< .001	0.32
(n = 22)	67 ms	61%	39%	< .001	0.11	78%	22%	< .001	0.28
	150 ms	60%	40%	< .001	0.10	70%	30%	< .001	0.20
	300 ms	57%	43%	< .001	0.07	68%	32%	< .001	0.18
Male	33 ms	65%	35%	< .001	0.15	86%	14%	< .001	0.36
(n = 20)	67 ms	68%	32%	< .001	0.18	79%	21%	< .001	0.29
	150 ms	67%	33%	< .001	0.17	72%	28%	< .001	0.22
	300 ms	65%	35%	< .001	0.15	72%	28%	< .001	0.22

Table 5-6 Mean (*SD*) of the response bias towards low-SF information in hybrid faces for female and male participants in Experiment 4 (pain-happiness hybrids).

		33 ms	67 ms	150 ms	300 ms
Female	**Low-SF pain** & high-SF happiness	15.32 (17.63)	10.32 (17.28)	10.09 (18.82)	6.77 (19.19)
(n = 22)	**Low-SF happiness** & high-SF pain	31.82 (13.33)	27.18 (12.82)	19.50 (12.02)	17.27 (16.80)
Male	**Low-SF pain** & high-SF happiness	14.05 (19.21)	17.10 (16.39)	15.75 (16.86)	13.80 (13.10)
(n = 20)	**Low-SF happiness** & high-SF pain	33.40 (10.62)	26.80 (14.63)	20.05 (19.59)	19.90 (16.89)

Statistical analysis revealed a significant main effect of presentation duration, F (3, 120) = 21.22, $p < .001$, $\eta^2_p = .35$. As before, the low-SF bias was greater when hybrid faces were presented for 33 ms than 67, 150, and 300 ms (all ps < .05, Cohen's ds > 0.45); and greater low-SF bias for 67 ms than 150 and 300 ms (both ps < .01, Cohen's ds > 0.55).

The main effect of expression was significant, F (1, 40) = 20.49, $p < .001$, $\eta^2_p = .34$. This indicated a greater low-SF bias when the low SF expression depicted happiness compared to pain ($p < .001$, Cohen's $d = 0.71$).

A significant interaction was also found between presentation duration and expression (Figure 5-3), F (2.46, 98.34) = 4.05, $p < .05$, $\eta^2_p = .09$. Simple effects analysis revealed that the effect of presentation duration was not significant when low-SF expression depicted pain, F (3, 38) = 1.21, $p = .32$. However, a significant effect of presentation duration was found for happiness, F (3, 38) = 11.91, $p < .001$, $\eta^2_p = .49$. Here, greater low-SF bias for happiness was found for 33 and 67 ms than 150 and 300 ms (all ps < .01, Cohen's ds > 0.54). Simple effects analysis also revealed a significant effect of expression type when presentation durations were at 33, 67, and 300 ms (all Fs > 6.28, ps < .05, η^2_ps > .13). Here, a greater low SF bias was found when the low-SF expression was happiness than pain (all ps < .05, Cohen's ds > 0.39). No significant difference was found when the presentation duration was set at 150 ms ($p = .06$).

In terms of sex difference, there was no significant main effect (F (1, 40) = 0.61, $p = .44$) or interaction (all Fs < 1.50, ps > .22).

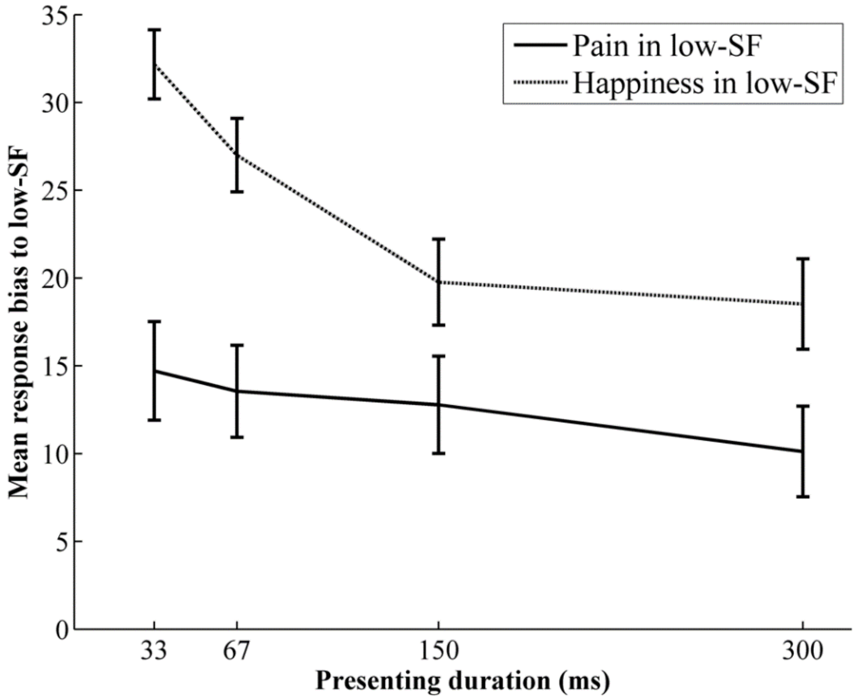

Figure 5-3 Mean response bias towards low-SF expressions when pain and happiness were presented in the low-SF component in hybrid faces with each presentation duration (error bars reflect *SEM*).

While the results of Experiment 4 suggested a bias towards low-SF information for both pain and happiness expressions, a greater low-SF bias was elicited by happiness compared to pain. More interestingly, when the competing high-SF was showing happiness, the bias towards low-SF pain was no longer modified by the presentation duration. These findings were observed for both male and female participants.

5.5 Effect of the competing emotional expression

In order to investigate whether the low-SF preference for pain expressions is mediated by the emotional content of pairing expressions in hybrid faces, I conducted another analysis to examine the effect of paired expression type (neutral vs. fear vs. happiness) on the low-SF bias for pain expressions. Data of response bias towards *low-SF pain* were entered into a 4 × 3 × 2 (Presentation Duration [33, 67, 150, 300 ms] × Paired Expression [neutral, fear, happiness] × Participant Sex [female, male]) mixed-groups ANOVA, where presentation duration was a within-groups variable, and paired expression and participant sex were between-groups variables.

Statistical analysis revealed that the main effect of paired expression is not significant ($F(2, 122) = 1.77$, $p = .17$), and none of the interactions was significant (all Fs < 1.49, ps > .21), which suggest that the emotional content of pairing expressions does not affect the low-SF preference for pain expressions.

5.6 Discussion

These three experiments examined whether low-SF or high-SF information is more salient for pain expressions. As expected, the recognition of pain expressions was preferentially based on low-SF information – pain expressions were more likely to be perceived when presented by low-SF compared to high-SF information. Moreover, this pattern was also found for the core emotions (i.e. neutral, fear, and happiness). This general perceptual bias towards low-SF information has been previously reported in categorization of emotional expressions (Laprevote et al., 2010; Schyns & Oliva, 1999). This is the first time it has been demonstrated for pain expressions.

This finding supports the hypothesis that the perception of pain expressions (like emotional expressions) is preferentially based on the low-SF information. Moreover, this is not affected by the emotional content of the pairing expressions in hybrid faces, which suggests that the low-SF preference for pain may be not context-specific but a more general processing property. Experiment 1 found that low-SF information was particularly more relevant for pain expressions compared to high-SF information. Thus, the preference of low-SF information suggests an efficient decoding process of pain expressions – the critical information is preferentially perceived by observers. However, this may not be generalised to the decoding of core emotions. According to the findings of Experiment 1, low-SF and high-SF information was equally informative for fear expressions, as well as happiness, and neutral expressions were more accurately recognised using high-SF information compared to low-SF. In this chapter, a general preference of low-SF information was found for all these core emotions, which indicates that, when processing core emotions, the characteristic SF component may not necessarily be preferentially perceived over the opposite in competitive situations (e.g. hybrids).

Although low-SF information seemed to play a general role in expression perception, there was a suggestion that the type of expression was important in some situations. For example, in Experiment 4, though a general preference towards low-SF information was observed, a greater low-SF bias was elicited by happiness compared to pain expressions. This expression difference was observed for happiness only, but not fear (Experiment 3) or neural (Experiment 2). The current finding for happiness is in line with that reported by Laprevote et al. (2010), who found that while the perception of expression was always biased towards the low-SF component in hybrid faces, a greater low-SF bias was found for happiness than anger expressions. These findings together suggest that when compared with a negative expression (e.g. pain or anger), happiness was better perceived from low-SF information.

Another key question addressed here was whether the preference of SF information for pain expressions would be modified by the presentation duration of hybrid faces. For all the three experiments, participants perceived expressions from the low-SF component, this was particularly prominent during the fast presentation, and somewhat reduced as the presentation duration increased. The largest low-SF bias was found when the hybrid faces were presented extremely briefly for 33 ms, as the presentation is prolonged, more responses were made to the high-SF expressions. This trend is in line with the previous finding on the hybrid scene perception that scenes presented by low-SF information were dominantly perceived at short durations, and the perception of high-SF scenes required more time (Schyns & Oliva, 1994). Moreover, for expression perception, the low-SF bias was found when the presentation duration was brief (i.e. 50 ms; Schyns & Oliva, 1999); and when the hybrid faces were presented for a longer time (i.e. 400 or 1000 ms), the expressions in the high-SF component were perceived as often as those in the low-SF (Deruelle & Fagot, 2005; Deruelle et al., 2008).

In the current experiments, although there was always a low-SF bias, the bias reduced as the presentation duration increased, which suggests that the expression presented in the high-SF component in hybrid faces could also be perceived, but just require longer viewing time. These temporal dynamics of low-SF and high-SF information could be accounted for by the distinct visual processing pathways for the two types of information. As discussed in Chapter 2, low-SF information is mainly conveyed by a relatively faster pathway with the neurones responding in a transient manner; whereas high-SF information mainly travels through a relatively slower pathway with the neurones responding in a more sustained manner. However, it is still unclear whether this temporal feature of the perceptual preference of SF information would be retained in the recognition of SF-filtered pain expressions: whether low-SF pain would require less time to be accurately recognised than high-SF pain.

It should be noted that one exception was found for the pain-happiness hybrids (Experiment 4) that when the pain was in the low-SF component and happiness high-SF, the bias towards low-SF pain was not affected by the presentation duration. Namely, the increase of the presentation duration did not make the high-SF happiness more visible when the paired expression was a pain. However, this was not found in the other two experiments, in which pain expression was paired with neutral and fear respectively. Thus one possible explanation is that the prominent characters of happiness may not be encoded in high-SF information, but mainly low-SF information, which also explains that why a greater low-SF bias was found when low-SF expressions depicted happiness rather than pain. More efforts would be necessary to reveal the reason behind.

In terms of sex difference, there was no significant main effect on the SF preference in any experiment. However, for the pain-neutral hybrids, when pain expressions were presented in the high-SF component, it dampens down females' low-SF bias towards neutral expressions, but not males'. Though there was still a low-SF bias, this finding suggests that the high-SF pain features do break through and enter women's visual perception in competitive situations (i.e. hybrids). This is an interesting effect that may be related to females' sensitivity to pain signals (Keogh & Holdcroft, 2002; Keogh, 2014) and worth considering further – e.g. why only observed when compared to neutral (i.e. non-expressive), but not other expressive facial expressions (e.g. fear and happiness)?

One limitation of these experiments is that the stimuli were synthesised hybrid faces, which combined two independent expressions, one in low-SF and one in high-SF. Although the hybrid paradigm has been successfully used in varies studies, the appearance of hybrid faces is unusual, and the perception could be different from that of a normal face. Thus, it should be very careful when to extend the findings and apply to the perception of facial expressions in the naturalistic environment.

In sum, the three experiments confirmed that low-SF information is perceptually preferred by observers for pain expressions. Thus, an efficient decoding process of pain expressions is suggested, in which the characteristic information is preferentially perceived and presumably effectively analysed. The experiments in this chapter also examined the temporal dynamics of SF information and observed that the low-SF preference was particularly conspicuous when the presentation was brief (e.g. 33 ms). It is thus of great interest to know whether this temporal advantage of low-SF information would be retained in the recognition of pain and whether low-SF information could lead to a more efficient decoding of pain expressions than high-SF information.

Chapter 6 Experiment 5: The role of SF information in pain recognition as a function of presentation duration

6.1 Introduction

As reported in Chapter 5, Experiments 2–4 examined the temporal feature of the perceptual preference of SF information using the hybrid paradigm. I found that low-SF pain expressions were perceived as particularly salient when presented briefly (e.g. 33 ms), and that this low-SF bias gradually diminished as the presentation duration increased. This indicates that information conveyed by low-SF is more likely to be perceived at an early stage of processing, and the processing of high-SF information may require longer time. However, the images presented in Experiments 2–4 were hybrids, and the temporal feature was examined for a perceptual bias (i.e. the likelihood of perceiving one of the two expressions in a hybrid face). It is therefore still unclear what role temporal factors have in recognising pain expressions using either low-SF or high-SF information.

In order to examine this idea that temporal properties of SF information are important, three subsequent experiments (Experiments 5–7) were planned to investigate the time course of SF information processing in the recognition of pain expressions. Experiment 5 was a preliminary examination to see whether the role of low-SF and high-SF information in pain recognition would be affected by the presentation duration of face stimuli (Chapter 6). Next, Experiment 6 employed the backward masking paradigm to disrupt the processing of SF information at multiple stages to investigate the time course of SF processing in early visual percept of pain expressions (Chapter 7). In Experiment 7, two modified backward masking tasks were used to explore the temporal dynamics of SF information further in pain recognition at two stages: information extraction and perceptual analysis (Chapter 8). In the current chapter, I will elaborate on the rationale for the first experiment in this series (Experiment 5). The rationale for Experiment 6 and 7 will be presented in the relevant introductions in subsequent chapters.

Experiment 5 aimed to directly examine the role of low-SF and high-SF information in the recognition of pain expressions as a function of presentation duration. This is because exposure time and image information both play a role in visual processing, yet have not been directed considered in pain. According to published research on facial expressions (see Chapter 2 section 2.4.2 for details), presentation duration seems to modulate the processing of SF information in emotional content perception. Thus, as a starting point, the temporal feature of SF information processing in pain recognition was examined as a function of stimuli presentation duration. If a particular type of SF information requires shorter presentation duration, the recognition performance of using that type of SF information would be better than the performance of using the information that requires longer presentation duration. The presentation durations of face stimuli used in Experiment 5 are 33, 67, 150, and 300 ms, which were consistent with Experiment 2–4 in this thesis. The core emotional expressions of fear, happiness, and neutral were also used to compare with pain. However, unlike the hybrid paradigm, in the current experiment, each face stimulus showed just one expression by either low-SF or high-SF information. It is hypothesised that pain expressions in SF information would be processed in a more efficient manner than those in high-SF – when the presentation duration was brief, the recognition of low-SF pain expressions would be more accurate than those presented by high-SF. The intact broad-SF face stimuli were also included for comparison. In addition, this study adopted the signal detection analysis (Macmillan & Creelman, 2004) of recognition accuracy to avoid possible response bias. The rationale and justification for this alternative approach to analysing the data are presented in the next section (Section 6.2.5).

6.2 Method

6.2.1 *Design*

Participants completed an expression categorization task using a mixed-groups design. The within-groups variables were the presentation duration (33 vs. 67 vs. 150 vs. 300 ms), type of SF information (broad-SF vs. low-SF vs. high-SF), and expression (pain vs. fear vs. happiness vs. neutral). A between-groups variable of participant sex (female vs. male) was also included. The dependent variable was recognition accuracy.

6.2.2 *Participants*

Forty-seven healthy adult participants (24 females and 23 males) were recruited from the University of Bath. Forty-six participants (23 females and 23 males) completed the study, with one female withdrawal. The sample had a mean age of 23.35 (*SD* = 4.31). The participation eligibility and exclusion criteria for recruitment were the same as in previous experiments. Ethical approval was granted by the Department of Psychology Ethics Committee (Ref. 13-161) and the Department of Health Ethics Committee (Ref. EP 13/14 33a) of the University of Bath. Informed consent was obtained from all participants before taking part in the study. Participants, who were first-year psychology students, were awarded one credit unit for participation; and all other participants were given £5 in return.

6.2.3 *Stimuli*

A total of 120 face images were taken from the stimulus set (Chapter 3 section 3.3) and used as stimuli in this experiment: Each actor (10 in total) displaying four facial expressions (pain, fear, happiness, and neutral) at three SF level (broad-SF, low-SF, and high-SF).

6.2.4 *Task*

The task was designed and controlled using E-Prime professional 2.0. The apparatus and display settings were the same as in the previous experiments. In this task, four fixed presentation durations were used, i.e. 33, 67, 150, and 300 ms, which was the same as the presentation durations used in Experiment 2–4, and justified there (Chapter 5 section 5.2.1.4). In this task, each participant completed 960 trials (i.e. the 120 face stimuli were presented twice within each of the four duration length conditions).

In each trial, participants were shown a fixation cross at the centre of the screen for 500 ms followed by a face stimulus. The face stimulus was presented one at a time, each for a given presentation duration and not masked. Each stimulus was randomly jittered over ±0.3°. Participants were asked to recognise whether the face was expressing fear, happiness, neutral, or pain by pressing the corresponding button on an SRBox as accurately and as quickly as possible. The buttons were labelled with the four expressions. A response could be made within 2000 ms from the onset of the stimulus, after which the trial terminated and moved onto the next trial, with or without response. Prior to the next trial, a blank page was displayed for 500 ms. The stimuli were presented randomly. Participants were able to take a break scheduled after every 240 trials. There was a practice of 20 trials preceding the main task. The face stimuli in practice were randomly selected from the 120 face stimulus images for each participant.

6.2.5 *Data preparation and analysis*

In this and subsequent experiments, participants' recognition accuracy was measured using signal detection estimates of sensitivity (Green & Swets, 1966; Macmillan & Creelman, 2004) rather than the simple hit rate. This is because the sensitivity measure provides a better way to quantify one's ability to discern a target stimulus (e.g. pain) from other distracting stimuli (e.g. other emotions) and is unaffected by response bias, as it examines not only the hit rate for targets but also the correct rejection rate for non-targets. For example, in this experiment, the estimated sensitivity to pain expressions measures observer's ability to accurately differentiate pain from fear, happiness, and neutral, which depends on both hits on pain expressions and correct rejections on non-pain expressions. Therefore, by using this approach, a response bias in favour of "pain" would not lead to a high recognition accuracy for pain expressions[10].

The sensitivity (*A'*) was calculated based on participants' responses (Macmillan & Creelman, 2004a, p. 101). An individual's sensitivity to the presence of a signal (i.e. the presenting expression) among a series of noises (i.e. other expressions in the experiment) could be estimated by the hit rate (*H*) and the false

[10] This approach was not used in Experiment 2–4, because the estimated sensitivity is a measure for accuracy, and there was no correct or incorrect response in these experiments but response bias measured. In addition, the sensitivity measure is only suitable for task with no more than six alternative categories (Neil A. Macmillan & Creelman, 2004). Thus, the simple hit rate was used in Experiment 1, as there were eight expression categories in the identification task, and for consistency and easier comparison, the same accuracy measure was used in the discrimination task as well.

alarm rate (*F*) of the presenting expression. For example, when pain is considered as a signal, the hit rate of pain is the probability of responding *pain* when pain expressions are presented, and the false alarm rate is the probability of responding *pain* when fear, happiness, or neutral expressions are presented. The sensitivity *A'* was calculated using the following equation (Macmillan & Creelman, 2004):

$$A' = \begin{cases} 0.5 + \dfrac{(H-F)(1+H-F)}{4H(1-F)}, \mathit{when}\, H \geq F \\ 0.5 - \dfrac{(F-H)(1+F-H)}{4F(1-H)}, \mathit{when}\, H < F \end{cases}$$

A' is a widely used non-parametric measure of sensitivity that does not assume signal or noise to be normally distributed or possess the same standard deviation (Macmillan & Creelman, 2004; Pollack & Norman, 1964; Stanislaw & Todorov, 1999). *A'* ranges from 0 to 1, where 0.5 is chance level performance, and 1 represents the perfect performance (Macmillan & Creelman, 2004). An example of *A'* calculation can be found in Appendix A.1. The calculation of *A'* was completed using MATLAB 2014.

During data analysis, I firstly examined whether the expressions could be recognised better than the chance level in each condition by comparing *A'* against the discrimination threshold of 0.75, which is halfway between chance and perfect performance. The threshold value of 0.75 was selected over 0.5 is because when compared against the chance level performance, the measure of discrimination sensitivity (e.g. *A'*) is more likely to have above chance performance than the forced-choice simple hit rate (Maxwell & Davidson, 2004). To control for this, the adjusted threshold value (i.e. 0.75) has been widely used in literature (Billimoria, Kraus, Narayan, Maddox, & Sen, 2008; J. L. Hall, 1998; Palmer, Huk, & Shadlen, 2005; Strauss & Allred, 1987; Ulrich & Vorberg, 2009; Wright & Barton, 2008). Therefore, the current experiment adopted the same approach and used one-sample *t*-tests to compared the *A'* against 0.75 in each condition.

The data of participants' sensitivity (*A'*) were then entered into a 4 × 3 × 4 × 2 (Presentation Duration [33 ms, 67 ms, 150 ms, 300 ms] × SF Information [broad-SF, low-SF, high-SF] × Expression [fear, happiness, neutral, pain] × Participant Sex [female, male]) mixed-groups ANOVA. Simple effects analyses were applied when significant interactions found. *Post hoc* analyses followed the same principles as described in Chapter 4.

6.3 Results

One male participant was excluded from further analysis due to lack of responses in multiple conditions. Afterwards, data were screened to remove trials with RTs shorter than 200 ms or longer than 2000 ms (1.98% of all trials). Final data for this study were from a sample of 45 participants (23 females and 22 males). For completeness, after removal of invalid trials, the simple hit rates[11] were calculated and are reported in Table 6-1.

The *A'* was calculated for each participant. No outlier was found, with *z*-scores lying within an acceptable range between -3.29 and 3.29. The data were approximately normally distributed (*z*-scores of skewness and kurtosis between -3.29 and 3.29), and approximately homogeneous (all Levene's *p*s > .170). For factors where sphericity could not be assumed, *F*-ratios with adjusted degrees of freedom and *p* values are reported below.

Mean and *SD* of the *A'* for female and male participants in each condition are presented in Table 6-2. All the descriptive statistics of *A'* are reported in three decimal places, as they range over a small span from 0 to 1. One-sample *t*-tests revealed that the *A'* for each facial expression in each condition was significantly higher than the discrimination threshold (0.75; two-tailed), all *t*s > 5.41, *p*s < .001, Cohen's *d*s > 0.80.

[11] To examine the validity of signal detection analysis in this type of research, participants' simple hit rate was also analysed in addition to estimated sensitivity. The same results were revealed in terms of the main effects and interactions. Thus, the results of analysis of estimated sensitivity are reported in this chapter, and the method of signal detection analysis was adopted in the following experiments of this thesis.

Table 6-1 The simple hit rate (%) for each expression presented for 33, 67, 150, and 300 ms by broad-SF, low-SF, and high-SF for female and male participants.

	Female (*n* = *23*)				Male (*n* = *22*)			
	33 ms	67 ms	150 ms	300 ms	33 ms	67 ms	150 ms	300 ms
Fear								
Broad-SF	80.27	80.93	77.43	83.48	79.46	80.28	80.28	86.22
Low-SF	76.99	81.31	78.13	79.11	83.86	77.17	80.00	81.94
High-SF	62.26	70.42	72.97	82.88	49.75	75.12	72.22	75.45
Happiness								
Broad-SF	90.75	86.18	88.79	87.11	94.71	87.56	90.18	87.39
Low-SF	88.00	82.27	87.22	88.55	85.96	87.39	86.16	86.88
High-SF	84.51	89.09	91.23	84.58	84.76	91.20	87.05	91.63
Neutral								
Broad-SF	74.11	78.92	77.93	80.36	80.63	82.59	82.43	80.09
Low-SF	70.22	74.31	75.33	75.45	78.41	75.00	78.38	82.46
High-SF	62.75	75.45	76.89	82.67	52.40	69.34	84.75	80.89
Pain								
Broad-SF	84.44	84.72	83.71	85.65	78.18	78.80	80.09	78.08
Low-SF	79.65	83.26	78.76	79.56	69.33	73.87	78.08	74.66
High-SF	62.15	75.00	82.30	82.30	52.61	54.33	68.78	72.27

Table 6-2 Mean (*SD*) of the *A'* for expressions presented for 33, 67, 150, and 300 ms by broad-SF, low-SF, and high-SF for females and males.

	Female (n = 23)				Male (n = 22)			
	33 ms	67 ms	150 ms	300 ms	33 ms	67 ms	150 ms	300 ms
Fear								
Broad-SF	.922 (.072)	.931 (.053)	.917 (.066)	.937 (.050)	.919 (.041)	.925 (.054)	.917 (.086)	.939 (.039)
Low-SF	.904 (.077)	.917 (.067)	.903 (.086)	.908 (.071)	.921 (.048)	.899 (.064)	.916 (.052)	.920 (.037)
High-SF	.864 (.115)	.895 (.074)	.903 (.078)	.938 (.049)	.814 (.105)	.913 (.060)	.918 (.055)	.917 (.048)
Happiness								
Broad-SF	.967 (.033)	.956 (.046)	.964 (.030)	.962 (.041)	.974 (.028)	.963 (.032)	.966 (.039)	.962 (.034)
Low-SF	.954 (.037)	.940 (.045)	.957 (.035)	.960 (.036)	.955 (.037)	.957 (.034)	.951 (.042)	.955 (.052)
High-SF	.889 (.087)	.943 (.037)	.961 (.041)	.944 (.047)	.864 (.073)	.922 (.036)	.944 (.058)	.959 (.046)
Neutral								
Broad-SF	.922 (.038)	.932 (.021)	.925 (.041)	.933 (.033)	.941 (.026)	.941 (.032)	.948 (.024)	.934 (.029)
Low-SF	.910 (.030)	.916 (.041)	.922 (.028)	.920 (.038)	.929 (.034)	.915 (.033)	.934 (.030)	.943 (.026)
High-SF	.865 (.064)	.917 (.039)	.924 (.036)	.938 (.029)	.804 (.103)	.896 (.057)	.938 (.037)	.932 (.027)
Pain								
Broad-SF	.925 (.060)	.926 (.053)	.919 (.057)	.937 (.045)	.915 (.069)	.916 (.063)	.928 (.049)	.922 (.047)
Low-SF	.909 (.086)	.935 (.041)	.904 (.081)	.916 (.054)	.892 (.086)	.892 (.078)	.921 (.064)	.915 (.066)
High-SF	.852 (.113)	.897 (.077)	.921 (.067)	.928 (.055)	.835 (.081)	.874 (.062)	.903 (.059)	.906 (.068)

A significant main effect of presentation duration was found, $F(2.79, 119.85) = 29.26$, $p < .001$, $\eta^2_p = .41$. The *A'* was lower for expressions presented for 33 ms than those presented for 67, 150, and 300 ms (all *p*s < .001, *d*s > 0.74), and lower *A'* was found for 67 ms than 300 ms ($p < .001$, $d = 0.70$). No other significant difference was found (both *p*s > .14). The main effect of SF information was significant, $F(2, 86) = 54.20$, $p < .001$, $\eta^2_p = .56$. The *A'* for broad-SF expressions was higher than that for low-SF ($p < .001$, $d = 0.71$) and high-SF expressions ($p < .001$, $d = 1.28$), and higher *A'* was found for low-SF than high-SF expressions ($p < .001$, $d = 0.87$). Significant main effect was found for expression, $F(2.45, 105.48) = 15.47$, $p < .001$, $\eta^2_p = .27$. Happiness was better recognised than fear, neutral, and pain (all *p*s < .001, *d*s > 0.85), but no other significant difference were found (all *p*s > .82).

A significant interaction was found between presentation duration and SF information (Figure 6-1), $F(5.24, 225.35) = 35.13$, $p < .001$, $\eta^2_p = .45$. Simple effects analysis was applied to examine the effect of presentation duration for each type of SF information. The presentation duration had a significant effect for high-SF only, $F(3, 41) = 30.79$, $p < .001$, $\eta^2_p = .69$. The *A'* for high-SF expressions increased continuously as the presentation duration increased from 33 to 150 ms (all *p*s < .001, *d*s > 0.52). No significant difference was found between 150 and 300 ms ($p = 1.00$). Participants' ability to recognise expressions presented by broad-SF and low-SF was not affected by presentation duration, both *F*s < 1.53, *p*s > .22. Further simple effects analysis was applied within each presentation duration condition, in order to examine the effect of SF information. For presentation duration of 33 ms ($F(2, 42) = 52.89$, $p < .001$, $\eta^2_p = .72$), the *A'* for broad-SF was higher than that for low-SF ($p < .05$, $d = 0.41$) and high-SF ($p < .001$, $d = 1.45$), and the *A'* was higher for low-SF than high-SF ($p < .001$, $d = 1.24$). For presentation duration of 67 ms ($F(2, 42) = 17.97$, $p < .001$, $\eta^2_p = .46$), the *A'* for broad-SF was higher than that for low-SF ($p < .01$, $d = 0.51$) and high-SF ($p < .001$, $d = 0.84$), but no significant difference between low-SF and high-SF ($p = .06$). The effect of SF information were not significant for expressions presented for 150 ms, $F(2, 42) = 2.88$, $p = .07$. For expressions presented for 300 ms ($F(2, 42) = 4.11$,

$p < .05$, $\eta^2_p = .16$), higher *A'* was found for broad-SF than low-SF ($p < .05$, $d = 0.42$), but no other difference was significant (both *p*s > .16).

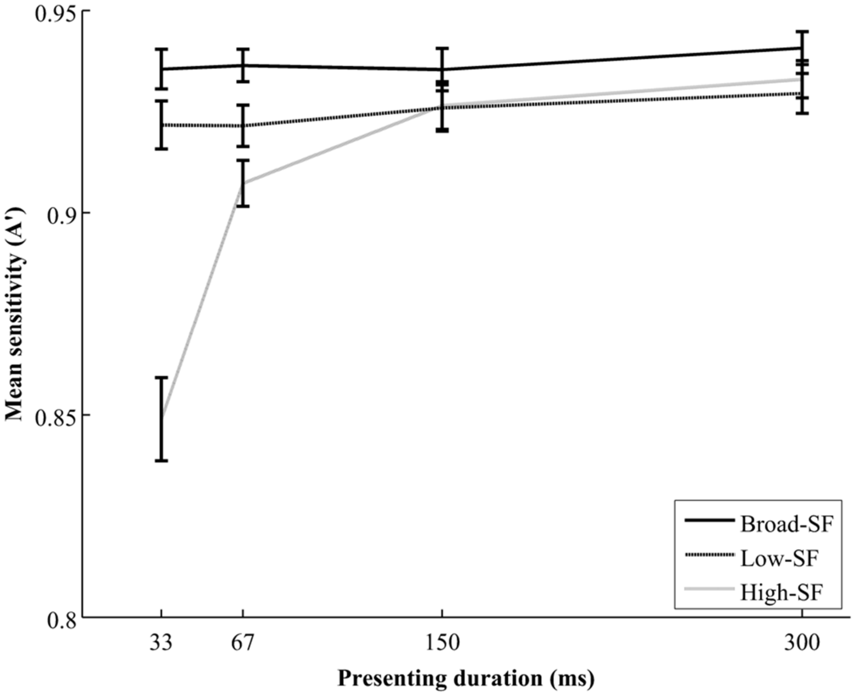

Figure 6-1 The mean sensitivity (*A'*) for expressions at each SF level presented for 33, 67, 150, and 300 ms (error bars represent *SEM*)

In terms of sex differences, the main effect of sex was not significant, $F(1, 43) = 0.17$, $p = .68$. The interaction between sex and SF information was significant (Figure 6-2), $F(1.77, 75.96) = 4.94$, $p < .05$, $\eta^2_p = .10$. Simple effects analysis did not reveal significant sex difference within any SF level (all *F*s < 2.02, *p*s > .16). The effect of SF information was significant for both females ($F(2, 42) = 12.07$, $p < .001$, $\eta^2_p = .36$) and males ($F(2, 42) = 31.84$, $p < .001$, $\eta^2_p = .60$), and similar pattern revealed. For both females and males, the *A'* for broad-SF expressions was higher than that for low-SF (for females: $p < .01$, $d = 0.67$; for males: $p < .01$, $d = 0.74$) and high-SF (for females: $p < .001$, $d = 0.85$; for males: $p < .001$, $d = 2.22$), and higher *A'* for low-SF than high-SF expressions (for females: $p < .05$, $d = 0.51$; for males: $p < .001$, $d = 1.44$). However, larger effect sizes were found for males compared to females due to relatively lower *A'* for high-SF expressions by male participants (see Figure 6-2), though it did not reach the significance level.

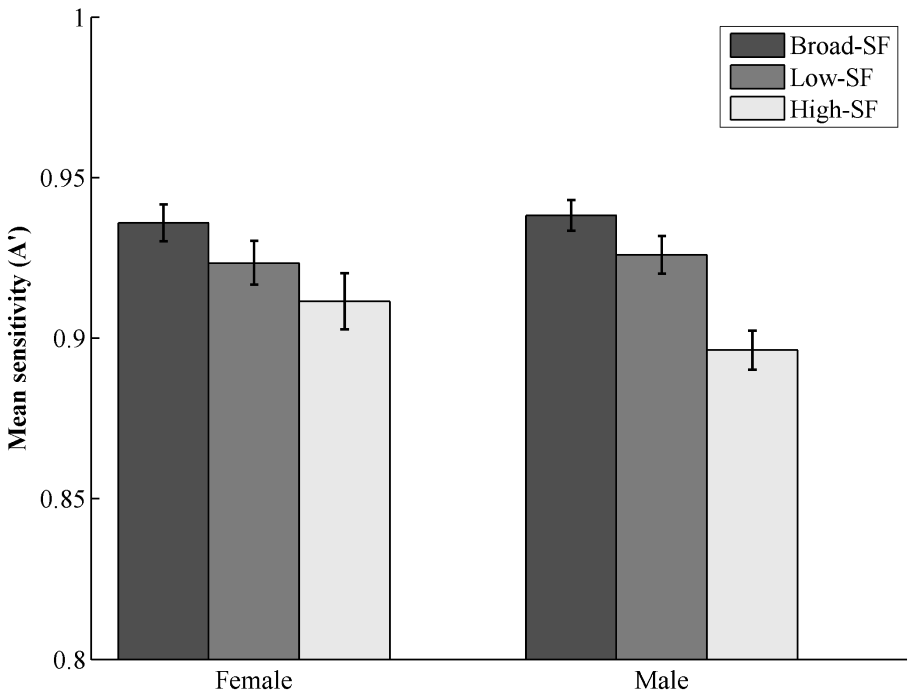

Figure 6-2 Female and male participants' mean sensitivity (*A'*) to expressions at each level of SF (error bars represent *SEM*).

No other interactions were significant, all Fs < 2.20, ps > .06.

6.4 Discussion

As the first step in the investigation of the time course of SF information processing for pain faces, this experiment examined the role of low-SF and high-SF information in the recognition of pain expressions as a function of presentation duration. The findings generally support the hypothesis that low-SF information was processed in a more efficient manner compared to high-SF information for pain recognition. However, such low-SF advantage was not specific to pain but found for all tested expressions (e.g. fear, happiness, and neutral). When the presentation duration was brief (i.e. 33 ms), the expressions, including pain, were better recognised with low-SF information compared to high-SF information. This is in line with Experiment 2–4 (Chapter 5) that found a temporal advantage for the perception of low-SF information.

The processing of low-SF and high-SF information has distinct temporal features in the recognition of expressions, including pain. At very early stages of processing, the role of low-SF and high-SF information in expression recognition is differently affected by the presentation duration of face stimuli. As expected, the processing of high-SF information required a longer time than low-SF information, and the recognition accuracy of high-SF expressions increased as the presentation duration became longer. In contrast, facial expressions presented by low-SF could be reliably identified when presented very briefly (i.e. 33 ms), and the performance was not affected by presentation duration. These findings suggest that the processing of low-SF expressions could be completed at a very early stage, whereas expressions presented by high-SF would require more time to be successfully decoded.

The efficient processing of low-SF information could help us understand the advantageous role of low-SF over high-SF information in pain recognition found in Experiment 1 (Chapter 4). One of the possible strengths of low-SF information lies in the temporal dimension, in that the processing of low-SF information may be more efficient compared to high-SF information. In Experiment 1, the presentation duration was set to a fixed value of 300 ms, which may not be adequate for high-SF information. Thus a low-SF advantage over high-SF was observed for pain recognition. In the current experiment, when the presentation duration was brief (e.g. 33 ms), the expressions were better recognised from low-SF than high-SF information. However, when the presentation duration increased, the low-SF advantage was eliminated.

It should be noted that, in the current experiment, the temporal advantage of low-SF was not only found for pain but also core emotions, and the presentation duration associated with low-SF advantage was much shorter than that in Experiment 1. These inconsistencies may be because different task parameters were used and different expression types involved in these two experiments. The identification task in Experiment 1 required participants to identify pain from eight possible expressions, which is considered more difficult than the task in the current experiment, where the pain was identified from four expression categories. In addition, the task parameters affect the role of SF information in various ways depending on the expression being processed. For example, the inconsistent pattern of SF information processing was found for pain and core emotions in the current experiment and Experiment 1, which suggests that the processing of SF information is not only affected by the expression type and task parameter as individual factors, but also the interaction between these factors.

Another important finding in this experiment is that the recognition of broad-SF and low-SF expressions revealed similar temporal features. Like low-SF expressions, facial expressions presented by intact broad-SF information could be reliably recognised when presented for 33 ms, and the accuracy did not improve along with an increase in presentation duration. This indicates that the recognition of facial expressions, including pain, may mainly rely on the coarse low-SF information. Though the accuracy was best when intact broad-SF information was available, either low-SF or high-SF information was sufficient for expression recognition, which is coherent with the finding of Experiment 1.

There were some additional findings that need to be considered here. In this experiment, happiness was recognised more accurately than other expressions, no matter which type of SF information was available. This is in-line with the finding of Experiment 1 in this thesis and previous studies (review: Calvo & Nummenmaa, 2015) that there is a happiness advantage in the expression recognition, though the underlying mechanism is still unknown. A second finding relates to sex difference. Here, females and males recognised core emotions in a similar manner, in terms of SF information processing, but slightly differed in pain recognition. Though this sex difference did not reach the significance level, it is worth to examine further whether females and males process SF information differently in the recognition of pain expressions in the following experiments.

There are also some limitations that should be noted, which in turn can be used to inform and improved in future studies. The findings of this experiment partly support the coarse-to-fine processing model that the low-SF information plays a key role in the early perception of facial expression and the perception of high-SF expressions gradually increases as the presentation duration increases. But it remains unknown whether the high-SF information would outperform low-SF information when adequate (i.e. unlimited) time is given. In the next experiment, the role of low-SF and high-SF information will be examined in expression recognition without any time constraint applied.

More importantly, from the findings of this experiment, it is difficult to infer the dynamics of the underlying processing of low-SF and high-SF information. As the first step in the investigation of the time course of SF information processing, the presentation duration was manipulated in this experiment. Although key to the processing of SF-filtered face information, the presentation duration of stimuli is not the processing time of visual information, as observers' perceptual processing of the information does not finish at the point of face stimuli offset (Ogmen & Breitmeyer, 2006). Thus, what I can conclude from this experiment is that low-SF information has an advantage in the temporal aspect of processing when compared to high-SF information, however, it is still unclear how long the processing of low-SF and high-SF information requires to make the recognition of pain expressions possible and whether this is also similar to emotional expressions. In the following chapter, I also plan to explore this further.

In sum, this experiment showed that pain expressions presented by the low-SF information required less presentation duration to be reliably recognised than those presented by high-SF information. A similar pattern was revealed for low-SF and broad-SF information; thus the coarse structural information could be identified as the main contribution to pain recognition. Moreover, these were not only found for pain expressions but also core emotions, which suggest that the recognition of pain may share similar visual perceptual properties with the recognition of emotional expressions, e.g. SF information processing.

Chapter 7 Experiment 6: The time course of SF information processing in the recognition of pain expressions

7.1 Introduction

As reported in Chapter 6, Experiment 5 preliminarily examined the temporal feature of SF information processing in pain recognition by manipulating the presentation duration of face stimuli and compared with core emotions (i.e. fear, happiness, and neutral). A temporal advantage was found for low-SF information, which was processed in a more efficient manner and required shorter presentation compared to high-SF information. This finding partly supported the coarse-to-fine processing hypothesis that low-SF information played a key role in the early processing of facial expressions, including pain, and high-SF required more time. However, as discussed in Chapter 6, two important questions remained unanswered: (1) what happens when adequate time is given, and (2) how long is needed to process low-SF and high-SF information in expression recognition. Both questions will now be considered in more detail in the current chapter.

First, it is not clear whether the low-SF or high-SF information would play a more prominent role at a later stage of processing, e.g. when the presentation duration and response time are unconstrained. The reason why this is important as because if low-SF information still outperforms high-SF when no time constraint is applied, then other mechanisms may be involved (other than the temporal aspect of processing). For example, the level of characteristicness of SF information may vary for different expressions. The second point is that although a temporal advantage was found for low-SF information over high-SF in Experiment 5, it is still difficult to infer the dynamics of underlying processing of low-SF and high-SF information in the recognition of facial expressions. For example, it is not clear how long is needed to process low-SF and high-SF information to make the recognition of pain possible, as the stimuli presentation duration does not correspond to observers' processing time of visual information (Ogmen & Breitmeyer, 2006).

Thus, in this chapter, Experiment 6 employed two tasks, a simple categorization task and a backward masking task, to study these two questions. To address question one, a simple categorization task was employed to examine the role of low-SF and high-SF information in the recognition of facial expressions of pain without any time constraints applied. In this task, the face images were constantly presented, and participants were instructed to carefully process the facial expressions and make accurate responses. According to the coarse-to-fine processing, it is expected that with sufficient time of viewing (presentation duration) and processing (response time allowance), high-SF information would exhibit an advantage over low-SF information.

In order to answer question two, a backward masking task was included to enable me to examine the time course of low-SF and high-SF information processing in the recognition of pain expressions. In Experiment 5, the presentation duration was manipulated. However, participants' processing of expressions does not terminate at the point of face stimuli offset but continues for hundreds of milliseconds after the stimulus offset (Rolls, 2007). This makes it difficult to infer the processing time of SF information from the presentation duration of face stimuli. To overcome this problem, the current experiment used the backward-masking paradigm to disrupt the processing of a target visual stimulus by a mask at various time points and examine the corresponding visual percept of the target stimulus (Ogmen & Breitmeyer, 2006). Different time points of processing could be accessed by manipulating the target and mask stimuli onset asynchrony (SOA) – the gap between the onset of the first stimulus (i.e. target) and the second stimulus (i.e. mask). In this experiment, the target face images were masked immediately after the presentation of the expression. Therefore, the time length that could be used to process the expression (i.e. target-mask SOA) is assumed to be equal to the target face presentation duration, after which the mask face intrudes into the percept and disrupts the processing of the target expression. Please refer to Figure 7-1 for illustration.

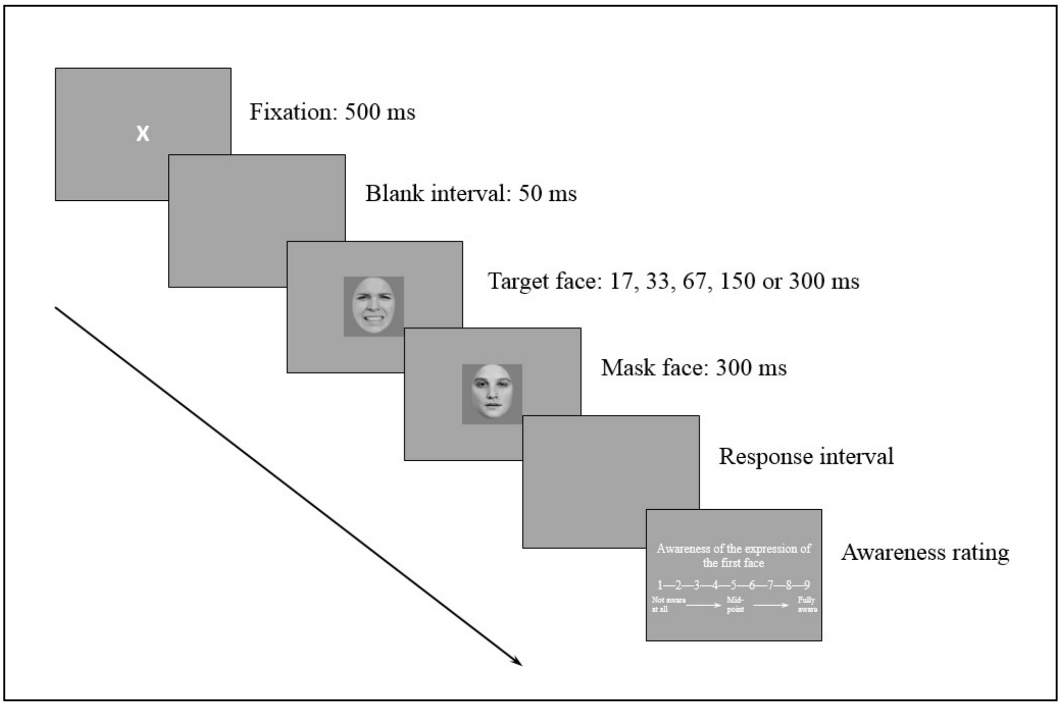

Figure 7-1 Details of trial procedure of the backward masking task.

Visual masking is a widely used and validated investigative tool in discovering the temporal properties of processes underlying visual perceptions (Breitmeyer & Ogmen, 2000; Breitmeyer, 2007; Ogmen & Breitmeyer, 2006; Wiens, 2006). More specifically, the backward masking paradigm has been widely used to investigate the temporal processing of emotional facial expressions, though mostly on those presented by intact (i.e. broad-SF) information (e.g. Aguado, Pedraza, & Gutierrez, 2014; Calvo & Lundqvist, 2008; Dimberg, Thunberg, & Elmehed, 2000; Esteves & Ohman, 1993; Kim et al., 2010; Maxwell & Davidson, 2004; Milders, Sahraie, & Logan, 2008; Neath & Itier, 2014; Ottaviani et al., 2012; Szczepanowski & Pessoa, 2007; Whalen et al., 1998). It has been found that facial expressions could be reliably decoded with exposure time (i.e. SOA) of approximately 120 ms on *average* (Esteves & Ohman, 1993), and the minimum exposure time for successful recognition varied according to the emotional content of the expression (Calvo & Lundqvist, 2008; Dimberg et al., 2000; Esteves & Ohman, 1993; Maxwell & Davidson, 2004; Milders et al., 2008; Neath & Itier, 2014). For example, happiness can be recognised more rapidly compared to other core expressions (e.g. anger, fear, and neutral). However, investigations of the time course of SF information processing in expression recognition have not been reported, especially with reference to pain. Many important questions are still left unanswered, such as how fast the painful information could be identified from facial expressions, whether this is similar to or different from core emotions and so on.

In the current experiment, the backward masking task was adopted to investigate the percept of SF information at different stages of early processing in the recognition of pain expressions. This task, therefore, examined the role of SF information as a function of target-mask SOA. It was hypothesised that in the backwards masking task, low-SF information would show an advantage over high-SF in the recognition of facial expressions of pain, which would be most apparent when the SOA was brief. The facial expressions of fear, happiness, and neutral were included in both tasks for comparison, which is consistent with my previous experiments.

7.2 Methods

7.2.1 *Design*

Participants completed a simple categorization task and a backward masking task, both of which used a mixed-groups design. For the simple categorization task, the within-groups variables were the type of SF information (broad-SF vs. low-SF vs. and high-SF), and expression (pain vs. fear vs. happiness vs. neutral). For the backward masking task, the within-groups variables were the target-mask SOA (17 vs. 33 vs. 67 vs. 150 vs. 300 ms), the type of SF information (broad-SF vs. low-SF vs. and high-SF), and expression (pain vs. fear vs. happiness vs. neutral). A between-groups variable of participant sex (female vs. male) was included in both tasks. The dependent variable was recognition accuracy in both tasks.

7.2.2 *Participants*

Forty-three healthy adult participants (22 females and 21 males) were recruited. The sample had a mean age of 24.91 (*SD* = 6.69). The participation eligibility and exclusion criteria for recruitment were the same as in previous studies. The participants were given £10 each in return.

7.2.3 *Stimuli*

The stimuli in both tasks were the same as those used in Experiment 5 (Chapter 6 section 6.2.3).

7.2.4 *Simple categorization task*

Each participant completed 120 trials with each stimulus image appearing once (i.e. 4 expressions × 3 SF levels × 10 actors). In each trial, participants were asked to view one face image at a time, all presented at the centre of the computer screen. They were asked to recognise the expression of each face by pressing the corresponding key labelled on the keyboard (i.e. fear, happiness, neutral, and pain). The face image was maintained on the screen until a valid response was given, and there was no time constraint for making a response. Participants were instructed to take the time required and respond as accurately as possible. The face images were presented in a random order.

7.2.5 *Backward masking task*

The target stimuli were 96 face images of 8 actors (4 females and 4 males) displaying pain, fear, happiness, and neutral at 3 SF levels (broad-SF, low-SF, and high-SF). The masks were 6 neutral faces displayed by the other 2 actors (1 female and 1 male) at the 3 SF levels. The neutral faces were used as masks because it has been found to be the most effective in masking face stimuli (Costen et al., 1994) and facial expressions (Milders et al., 2008), compared to non-face masks. The presentation duration of a target face stimulus in this task could be 17, 33, 67, 150, or 300 ms. According to Experiment 5, the low-SF expressions were reliably identified when presented for 33 ms, though without masking. Thus, in this task, an extreme brief presentation duration of 17 ms [12] was included to study the SF processing at a very early stage.

[12] 17 ms was selected due to the refresh rate of the monitor, which is 60 Hz. Thus the minimum presentation duration of one frame is 1/60 = 0.0167 seconds.

For each trial (see Figure 7-1), participants were shown a fixation cross at the centre of the screen for 500 ms followed by a blank screen for 50 ms prior to the target face onset, in order to reduce any priming effect of the fixation cross. A target face was presented for either 17, 33, 67, 150, or 300 ms, and was immediately replaced by a neutral face mask. Thus, in this task, the time interval between the onset of a target stimulus and the onset of a mask (i.e. target-mask SOA) was equal to the presentation duration of the target face. The duration of the mask was fixed at 300 ms, which was found to be able to effectively mask the target (Esteves & Ohman, 1993; Macknik & Livingstone, 1998; Pessoa, Japee, & Ungerleider, 2005). In each trial, the model gender and the SF condition of the mask face image always matched with the target face image, but the identities were always different.

This task required two sets of responses – judgement of the target face expression and rating of the awareness of the expression (Rabin & Cain, 1984). The inclusion of awareness rating allows the participants to make graded reports about the degree of their perception (Macmillan & Creelman, 2004) and provides additional information to improve the assessment of the very subtle perceptual changes at early stages of processing that the forced-choice accuracy may not be sensitive enough to reveal. As a matter of fact, recognitions of the same level of accuracy may involve different levels of processing and knowledge of the expressions. For example, equal number of correct responses could be made to faces presented for 17 ms and 33 ms, where the 17 ms' responses may be completely made by guessing (i.e. random choices made without being aware of the expressions), but the 33 ms' made with some level of awareness to the expressions. By measuring the level of the awareness in this way, I was able to evaluate the influence of each response on the overall recognition accuracy, e.g. a hit with low awareness has less weight than one with high awareness. Thus, the calculated accuracy represents participants' perception and understanding of the expressions at a better level of precision. The calculation is reported in detail in the section 7.2.6 of this chapter.

In this fashion, participants were firstly asked to recognise whether the target face was expressing fear, happiness, neutral, or pain by pressing the corresponding key labelled on the keyboard as quickly and as accurately as possible. A recognition response was allowed be made and recorded within 2000 ms since the onset of target stimulus. After this, with or without a response, participants rated their awareness to the expression of the target face on a 9-point scale by pressing the corresponding key from *1* to *9* on the keyboard: *1* = “not aware at all”, *9* = “fully aware”, and *5* = “mid-point”. There was no time limit for the awareness rating. There was an interval of 1000 ms in between of each trial.

Participants were instructed that there would always be two faces in each of the trials, and the target face was always the first one, though the first face could sometimes be presented extremely quickly. They were instructed to respond to the expression of the first face they saw. In this task, each participant completed 960 trials (i.e. 96 target stimuli, 5 SOAs, and each repeated twice) with a break after every 192 trials. There was a practice of 20 trials preceding the main task. The target face stimuli in practice were randomly selected for each participant. All participants were asked to complete the backward masking task first, and then the simple categorization task, to avoid any potential priming effect.

7.2.6 *Data preparation and analysis*

Data from the simple categorization task and the backward masking task were analysed separately. Participants’ recognition accuracy in the two tasks were again analysed following the signal detection theory (Green & Swets, 1966; Macmillan & Creelman, 2004). Sensitivity scores were calculated using different methods depending on the task. In the simple categorization task, the dependent variable was participants’ sensitivity (*A’*), which was calculated following the same procedure as in Experiment 5 (Chapter 6 section 6.2.5). Data were then entered into a 3 × 4 × 2 (SF Information [broad-SF, low-SF, high-SF] × Expression [fear, happiness, neutral, pain] × Participant Sex [female, male]) mixed-groups ANOVA.

In the backward masking task, the graded awareness was reported in each trial, which gives access to the degree of participant’s perception of the expression and determines multiple criteria of judgement (Macmillan & Creelman, 2004). To use these ratings to improve the assessment of participants’ performance, I calculated the sensitivity measure (A_g) based on the responses at each awareness level (Macmillan & Creelman, 2004b, p. 102). The sensitivity A_g was calculated using the following equation (Macmillan & Creelman, 2004):

$$A_g = \frac{1}{2}\sum (F_{i+1} - F_i)(H_{i+1} + H_i)$$

Here F is the false alarm rate, and H is the hit rate. The index i refers to the awareness rating. Similar to *A'*, the A_g is a non-parametric measure of estimated sensitivity that ranges from 0 to 1, where 0.5 is the chance level performance. For a detailed description of calculation and example, please refer to Appendix A.2. The calculation was completed using MATLAB 2014. In this task, the dependent variable was estimated sensitivity (A_g). Data were entered into a 5 × 3 × 4 × 2 (SOA [17 ms, 33 ms, 67 ms, 150 ms, 300 ms] × SF Information [broad-SF, low-SF, high-SF] × Expression [fear, happiness, neutral, pain] × Participant Sex [female, male]) mixed-groups ANOVA. For both of the tasks, simple effects analyses were applied when significant interactions found. *Post hoc* analyses followed the same principles as described in Chapter 4.

The data of awareness rating were not analysed in addition to recognition accuracy. This is because when analysing the awareness data, the rating on accurate and inaccurate responses should be considered separately. However, in this study, the extremely small number of accurate responses was expected in very challenging conditions (e.g. expressions presented for 17 ms), and very few inaccurate responses in those unchallenging ones (e.g. expressions presented for 300 ms). Thus, the number of responses was not adequate to produce reliable mean awareness rating in multiple conditions.

7.3 Results

7.3.1 *Simple categorization task*

The simple hit rates were calculated for completeness (see Table 7-1). The *A'* was calculated for each participant. No outlier was found for the overall *A'*, with *z*-scores ranging from -3.29 to 3.29. Data from all the participants (22 females and 21 males) were included here. The data were approximately normally distributed (z-scores of skewness and kurtosis between -3.29 and 3.29), and homogeneous (all Levene's *p*s > .11).

Mean and *SD* of the *A'* for female and male participants are presented in Table 7-2. One-sample *t*-tests (two-tailed) revealed that the *A'* for all the facial expressions in each condition were significantly higher than the discrimination threshold (0.75), all *t*s > 27.78, *p*s < .001, *d*s > 4.23.

Table 7-1 The simple hit rate (%) for each expression at each SF level in the backward masking task with each SOA and the simple categorization task.

	Female						Male					
	17 ms	33 ms	67 ms	150 ms	300 ms	Simple	17 ms	33 ms	67 ms	150 ms	300 ms	Simple
Fear												
Broad-SF	30.72	49.71	73.99	90.91	90.12	92.05	26.35	44.37	63.19	85.63	91.52	92.86
Low-SF	31.06	58.72	74.86	84.00	92.53	92.61	26.67	47.74	65.00	85.03	87.27	90.48
High-SF	8.18	24.24	47.06	73.14	86.13	89.77	6.71	16.67	28.19	67.70	73.49	88.10
Happiness												
Broad-SF	20.37	41.52	70.11	89.71	92.53	89.77	21.85	43.51	64.02	83.64	89.82	91.67
Low-SF	21.74	40.24	69.01	89.66	92.44	90.34	25.53	34.84	58.64	84.76	90.42	92.86
High-SF	23.57	40.37	63.01	83.52	88.64	89.20	29.14	40.28	55.90	81.82	88.02	91.67
Neutral												
Broad-SF	51.90	44.10	55.23	77.84	84.21	89.20	48.28	36.43	60.49	79.17	87.88	91.07
Low-SF	47.83	35.29	60.92	78.74	86.86	90.34	45.45	34.90	57.96	75.61	86.06	92.86
High-SF	69.54	49.38	56.21	73.26	82.29	89.77	59.12	51.05	47.26	77.02	85.54	88.69
Pain												
Broad-SF	33.13	41.86	70.11	85.80	89.71	93.18	37.33	56.69	73.62	84.24	89.22	91.07
Low-SF	33.33	46.78	68.60	85.23	86.21	88.64	31.72	48.72	70.30	89.82	90.91	91.07
High-SF	16.15	33.73	52.00	68.39	78.74	85.80	16.56	39.22	52.23	67.07	77.11	83.93

Note: 17 ms, 33 ms, 67 ms, 150 ms and 300 ms are SOAs in the backward masking task, and the “Simple” condition refers to the simple categorization task. The number of participants is not reported in this table, as the data in this table are from two tasks and different numbers of participants were included for analysis.

Table 7-2. Mean (*SD*) of the *A'* for each expression at each SF level in the simple categorization task.

		Female (n = 22)	Male (n = 21)
Fear			
	Broad-SF	.963 (.033)	.978 (.033)
	Low-SF	.962 (.048)	.973 (.037)
	High-SF	.958 (.037)	.960 (.038)
Happiness			
	Broad-SF	.974 (.048)	.964 (.047)
	Low-SF	.971 (.031)	.975 (.026)
	High-SF	.968 (.038)	.962 (.046)
Neutral			
	Broad-SF	.967 (.021)	.964 (.025)
	Low-SF	.962 (.032)	.975 (.021)
	High-SF	.960 (.031)	.954 (.030)
Pain			
	Broad-SF	.974 (.029)	.974 (.031)
	Low-SF	.965 (.039)	.969 (.031)
	High-SF	.964 (.037)	.948 (.058)

A significant main effect of SF information was found, $F(2, 80) = 4.43$, $p < .05$, $\eta^2_p = .09$. Higher *A'* was found for broad-SF expressions than that for high-SF expressions ($p < .05$, $d = 0.39$), but no other significant difference was found (both *p*s > .08). None of the other main effect or interactions were found to be significant, all *F*s < 1.69, *p*s > .19.

These results did not support the hypothesis. Without time constraints, no difference was found between the recognition of facial expressions presented by low-SF and high-SF information. This was not only found for pain expressions but also core emotions. The recognition of happiness did not show any advantage in this task.

7.3.2 *Backward masking task.*

Data were firstly screened for invalid responses made within 200 ms or after 2000 ms since stimulus onset. One participant (female) was excluded from further analysis due to few valid responses made in multiple conditions. Final data for this analysis were from a sample of 42 participants (21 females and 21 males). For completeness, after removal of invalid trials (2.39% of all trials), the simple hit rates were calculated and are reported in Table 7-1. The A_g was calculated for each participant. No outlier was found (z-scores ranging from -3.29 to 3.29), and the data were normally distributed (z-scores of skewness and kurtosis between -1.96 and 1.96). The data were approximately homogeneous (all Levene's *p*s > .06).

Mean and *SD* of the A_g for female and male participants in each condition are presented in Table 7-3. One-sample *t*-tests (two-tailed) revealed that for all the facial expressions presented by broad-SF and low-SF information, the A_g was significantly higher than the discrimination threshold (0.75) when the SOA was 67, 150 and 300 ms (all *t*s > 2.53, *p*s < .05, *d*s > 0.39); for expressions presented by high-SF information, the A_g was significantly higher than the threshold (0.75) when the SOA was 150 and 300 ms (all *t*s > 3.81, *p*s < .001, *d*s > 0.58).

Table 7-3 Mean (*SD*) of the A_g for each expression at each SF level with each SOA for female and male participants in the backward masking task.

	Female (n = 21)					Male (n = 21)				
	17 ms	33 ms	67 ms	150 ms	300 ms	17 ms	33 ms	67 ms	150 ms	300 ms
Fear										
Broad-SF	.577 (.137)	.711 (.140)	.830 (.153)	.932 (.100)	.955 (.043)	.584 (.106)	.616 (.154)	.794 (.168)	.944 (.056)	.948 (.047)
Low-SF	.573 (.139)	.715 (.162)	.852 (.153)	.936 (.089)	.965 (.061)	.582 (.106)	.640 (.142)	.801 (.148)	.926 (.088)	.964 (.041)
High-SF	.456 (.142)	.616 (.130)	.708 (.173)	.894 (.120)	.921 (.080)	.494 (.117)	.590 (.116)	.651 (.125)	.836 (.120)	.935 (.050)
Happiness										
Broad-SF	.613 (.139)	.690 (.176)	.852 (.099)	.943 (.074)	.955 (.065)	.570 (.128)	.717 (.152)	.850 (.152)	.946 (.064)	.967 (.040)
Low-SF	.583 (.151)	.710 (.144)	.838 (.131)	.931 (.069)	.948 (.061)	.600 (.112)	.692 (.108)	.810 (.146)	.945 (.050)	.966 (.044)
High-SF	.523 (.088)	.560 (.140)	.747 (.135)	.869 (.103)	.926 (.070)	.513 (.124)	.576 (.122)	.693 (.117)	.877 (.097)	.910 (.096)
Neutral										
Broad-SF	.609 (.099)	.710 (.128)	.856 (.106)	.927 (.087)	.948 (.055)	.564 (.106)	.681 (.153)	.816 (.131)	.931 (.060)	.955 (.036)
Low-SF	.592 (.114)	.667 (.147)	.858 (.134)	.928 (.073)	.960 (.049)	.581 (.118)	.641 (.153)	.822 (.098)	.927 (.075)	.950 (.049)
High-SF	.574 (.109)	.661 (.136)	.756 (.133)	.892 (.088)	.916 (.079)	.566 (.090)	.643 (.108)	.727 (.124)	.884 (.097)	.912 (.065)
Pain										
Broad-SF	.539 (.095)	.654 (.149)	.836 (.139)	.949 (.075)	.958 (.072)	.597 (.128)	.663 (.129)	.813 (.139)	.922 (.094)	.941 (.062)
Low-SF	.564 (.134)	.689 (.187)	.851 (.121)	.938 (.068)	.965 (.054)	.526 (.139)	.571 (.172)	.785 (.113)	.947 (.056)	.957 (.045)
High-SF	.536 (.151)	.597 (.195)	.717 (.178)	.850 (.138)	.912 (.075)	.581 (.123)	.550 (.161)	.659 (.147)	.803 (.119)	.884 (.120)

A significant main effect of SOA was found, $F(2.45, 97.86) = 492.34$, $p < .001$, $\eta^2_p = .92$. Participants' sensitivity (A_g) increased along with the SOA continuously from 17 ms to 300 ms, where the increase of A_g was significant between each of the two adjacent SOAs (all ps < .001, ds > 0.78). The main effect of SF information was significant, $F(2, 80) = 96.87$, $p < .001$, $\eta^2_p = .71$. The A_g for broad-SF and low-SF expressions was higher than that for high-SF expressions (both ps < .001, ds > 1.77), but no significant difference was found between broad-SF and low-SF ($p = 1.00$).

The interaction between SOA and SF information was significant (Figure 7-2), $F(5.64, 225.72) = 4.75$, $p < .001$, $\eta^2_p = .11$. I examined the effect of SOA on each SF information, and the SF difference at each level of SOA, separately. The effect of SOA was significant for each SF, all Fs > 170.99, ps < .001, η^2_ps > .94. For broad-SF, the A_g increased along with the SOA continuously from 17 ms to 150 ms (all ps < .001, ds > 1.07), but no significant difference between 150 ms and 300 ms ($p = .46$). For low-SF and high-SF, the A_g increased continuously from 17 ms to 300 ms (all ps < .01, ds > 0.60). Significant SF difference was found at each level of SOA (Fs > 6.95, ps < .01, η^2_ps > .26), and a similar pattern was revealed that the A_g for broad-SF and low-SF were higher than that for high-SF at each SOA (all ps < .05, ds > 0.44).

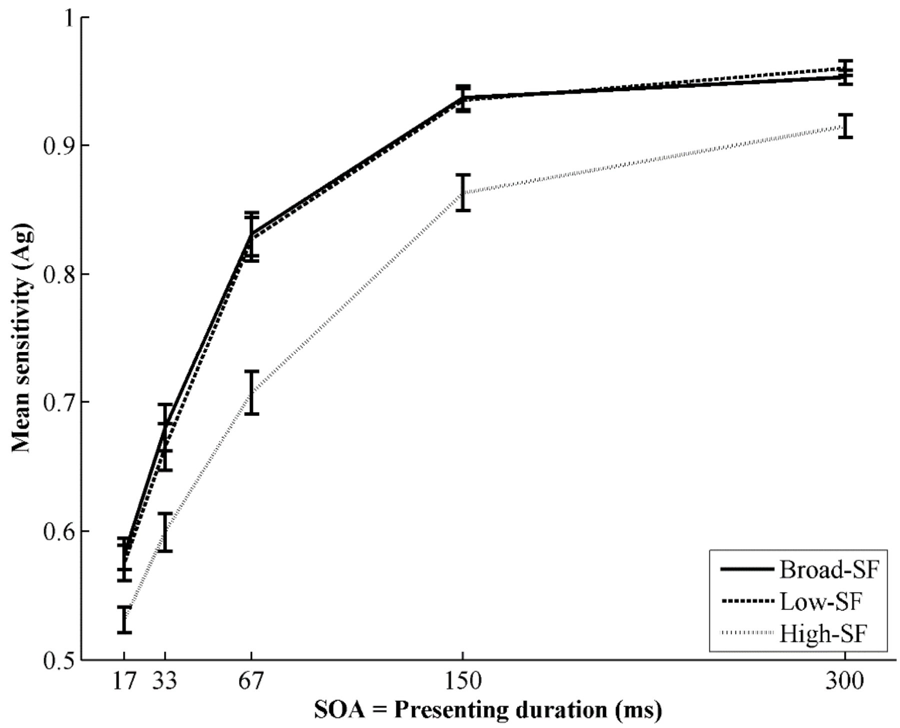

Figure 7-2 Mean sensitivity (A_g) for backward masked expressions at each SF level with each SOA (error bars represent *SEM*).

The main effect of expression type was significant with small effect size, $F(2.53, 101.05) = 3.17$, $p < .05$, $\eta^2_p = .07$, however, after correction no significant difference was found between expressions (all *p*s > .07).

The interaction between SF information and expression was significant (Figure 7-3), $F(4.62, 184.61) = 3.71$, $p < .01$, $\eta^2_p = .09$. The effect of SF information was significant for all the expressions (all *F*s > 14.29, *p*s < .001, η^2_ps > .42), and a similar pattern was revealed. The broad-SF and low-SF expressions were better identified than the high-SF expressions (all *p*s < .01, *d*s > 0.58). The effect of expression type was significant for high-SF only ($F(3, 38) = 8.39$, $p < .001$, $\eta^2_p = .40$), where higher A_g was found for neutral than other expressions (all *p*s < .05, *d*s > 0.49). This may be because the mask images were neutral faces and will be returned to in the discussion (section 7.4 of this chapter).

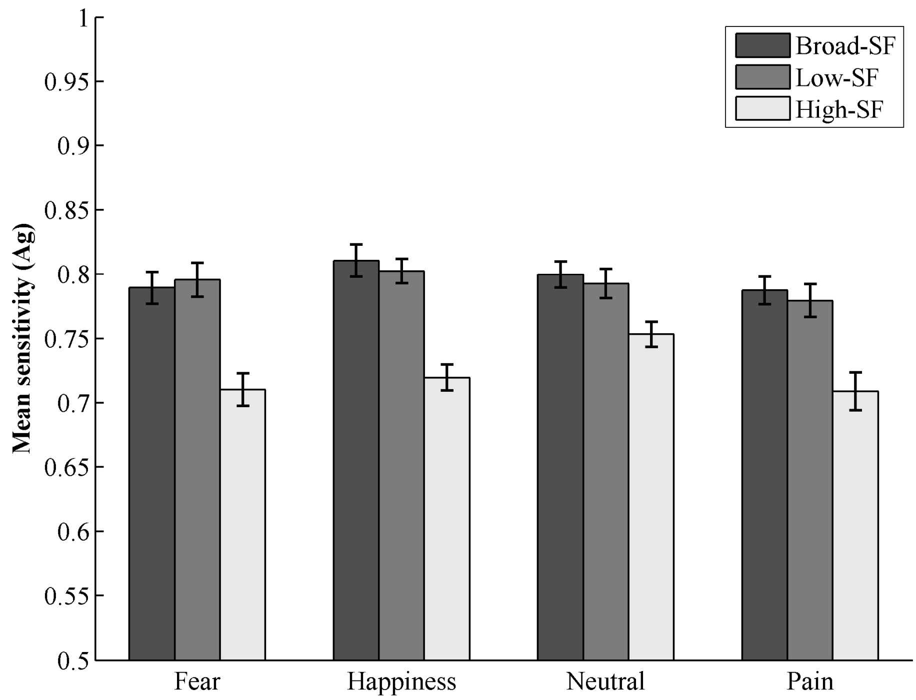

Figure 7-3 Mean sensitivity (A_g) for fear, happiness, neutral and pain at each SF level (error bars represent *SEM*).

The interaction of SOA × SF Information × Expression was significant with a small effect size (Figure 7-4), $F(11.98, 479.26) = 2.36$, $p < .01$, $\eta^2_p = .06$. I examined the effect of SOA and SF information for each expression type separately.

A significant effect of SOA was found for each expression at each SF level, all Fs > 77.57, ps < .001, η^2_ps > .89. For broad-SF, a similar pattern was revealed for all the expressions that the A_g increased continuously from 17 ms to 150 ms (all ps < .05, ds > 0.52). For low-SF, a similar pattern was revealed for happiness, neutral and pain that the A_g also increased from 17 ms to 150 ms (all ps < .05, ds > 0.47); whereas for low-SF fear, the A_g increased from 17 ms to 300 ms (all ps < .01, ds > 0.56). For high-SF, a similar pattern was revealed for happiness and pain that the A_g increased from 33 ms to 300 ms (all ps < .05, ds > 0.49). For high-SF neutral, the A_g increased from 17 ms to 150 ms (all ps < .01, ds > 0.59). For high-SF fear, the A_g increased from 17 ms to 300 ms (all ps < .05, ds > 0.47).

On the other hand, significant SF differences were found for all the expressions at all the SOA levels (all Fs > 4.18, ps < .05, η^2_ps > .17), except neutral with SOA of 17 and 33 ms, and pain with 17 ms (all Fs < 2.41, ps > .10). Where significant effects found, a similar pattern was revealed, in that the broad-SF and low-SF expressions were better identified than the high-SF ones (all *p*s < .05, *d*s > 0.41). However, there are two exceptions – fear with SOA of 300 ms, where higher A_g was only found for low-SF than high-SF (p < .01, d = 0.56); and pain with 33 ms, where higher A_g was only found for broad-SF than high-SF (p < .05, d = 0.44).

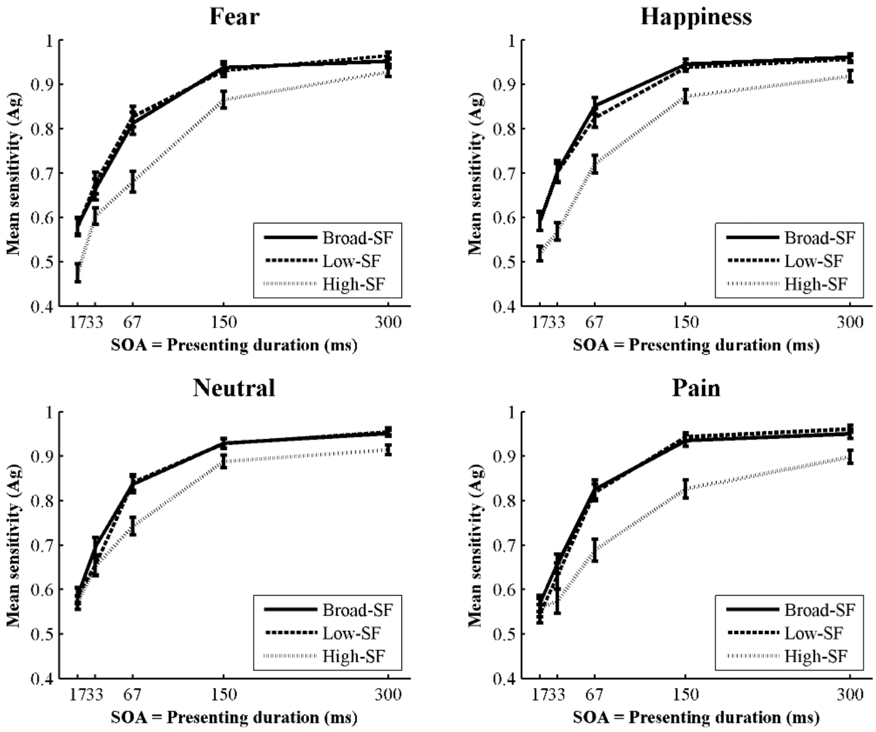

Figure 7-4 Mean sensitivity (A_g) for fear, happiness, neutral and pain at each SF level with each SOA (error bars represent *SEM*)

In terms of sex difference, the main effect of participant sex was not significant, $F(1, 40) = 0.85$, $p = .36$, and none of the interactions were significant, all *F*s < 1.68, *p*s > .11.

7.4 Discussion

This experiment consisted of two tasks – a simple categorization task and a backward masking task. The simple categorization task found that low-SF and high-SF information were equally informative for pain recognition, when no time constraint was applied, which suggests that the advantage of low-SF information may indwell in the temporal aspect of processing. More importantly, this was not only found for facial expressions of pain, but also core emotions. Interestingly, the happiness advantage was not shown in this task, where participants could view the face stimuli freely and make responses without time limits, all the expressions were recognised highly accurately. This point will be discussed in more detail as below.

The backward masking task, enabling very brief exposure to the face stimuli, found an advantage of low-SF information over high-SF information at early stages of the recognition of pain, as well as for the core emotions. This result supports the hypothesis that the high-SF filtered pain expressions require more time to be reliably recognised than those presented by low-SF or intact (broad-SF) information. A similar role was found for broad-SF and low-SF information, which suggests that the low-SF information could be the main contribution to rapid detection of pain. More importantly, this pattern was also found for the tested core emotions (fear, happiness, and neutral), which is consistent with the temporal features found in Experiment 5 and suggests that the recognition of pain expressions shares similar visual perceptual properties with core emotions, for example, SF information processing.

The current experiment also found evidence to suggest that facial expressions of pain could be accurately perceived on an ultra-fast time scale – successful decoding of intact or low-SF filtered pain faces occurred within 150 ms. Although the time course of accurate recognition of pain had not been systematically examined before, fast detection of pain out of facial expressions has been reported in a recent study (Czekala et al., 2015), where detection occurred within 100 ms to 200 ms. In addition, this is comparable to the time course for successful recognitions of core emotions (Calvo & Nummenmaa, 2009; Esteves & Ohman, 1993; Neath & Itier, 2014), which required approximately 100 ms to 200 ms depending on the task parameters and the emotional content.

The current experiment found that the fast recognition of pain and core emotional expressions mainly relied on the processing of coarse low-SF information. In particular, when the face images were backwardly masked, the recognition performances of using low-SF and broad-SF information were indistinguishable. This result evidences the important role of low-SF information in expression recognition – at early stages of processing, the judgement of an expression can be mainly contributed by our understanding of the overall quality conveyed by low-SF information. On the other hand, it also indicates that high-SF information did not make a significant contribution to the very early processing of facial expressions.

Together, these findings demonstrate that backward masking obstructed the processing of high-SF information, but allowed the low-SF processing to remain intact – implying that there may be different mechanisms underlying the processing of low-SF and high-SF information in facial expression perception. It is known that visual perception is comprised of two distinct processes, namely feed-forward and recurrent processing (Lamme & Roelfsema, 2000). Backward masking functions to disrupt the recurrent processing of the target. When the higher level requires access to re-enter the lower level representation of the earlier presented target, the mask has already replaced or interact with the target stimulus, resulting in conflicts or confusions in perception (Enns, Lleras, & Di Lollo, 2006; Fahrenfort, Scholte, & Lamme, 2007; Hegdé, 2008). However, the feed-forward processing is less affected by the masking, as it requires less feedback processing and top-down control. Therefore, the results of the current experiment could suggest that in facial expression perception, low-SF coarse information may require less feedback processing and accordingly be less sensitive to backward masking, whereas high-SF information may be largely processed in a recurrent manner and so require more top-down control and re-assessing of the representation of the expressions.

The feedforward vs. recurrent processing also helps explain why the recognition of facial expressions displayed by low-SF information was much faster than those displayed by high-SF information. The backward masking task found that successful recognition of low-SF expressions required the target-mask SOA of approximately 150 ms, whilst high-SF expressions required much longer SOA to recognise (i.e. more than 300 ms). The target-mask SOA allows me to access the processing of a target stimulus at various time points. When the target could be reliably recognised, the corresponding SOA is considered as the approximate duration that required to accomplish the related processing. It has been proposed that the processing duration of 150 ms would not be adequate to perform sophisticated feedback processing for a complex visual-related task (Thorpe et al., 1996), because of a large number of processing stages involved. For example, visual signals require at least 100–200 ms to transmit feed-forwardly to the prefrontal cortex to make the judgment of categorization (Bullier, 2001; Thorpe, 2001). This again suggests that, in expression perception, the coarse low-SF information seems to be processed mainly in a feed-forward manner, and the fine-detailed high-SF information recurrently.

If the coarse low-SF elements in a facial expression could be processed rapidly in a feed-forward manner, this may be socially adaptive. In the natural environment, our vision changes constantly. Often we can only see a facial expression at a fleeting glance, and then the face would be quickly "masked" by other visual input in various formats (e.g. objects, scenes, or another face). It would, therefore, be beneficial to quickly process the coarse overall quality of a facial expression in a feed-forward manner, and accordingly rapidly detect other's internal experience in such situations, particularly for those signal threatening information or elicit help (e.g. pain).

This experiment also produced some unexpected effects. For example, similar to previous experiments, there was little evidence for any sex differences in the SF processing for pain or emotional expressions. In addition, in the backward masking task, the neutral expressions were recognised more accurately than other expressions when presented by high-SF information. This may be explained by the integrating effect of the masking. The emotional content in the masks matched with the target expressions of neutral, when they were in very challenging visual conditions and presented briefly, the neutral masks might be integrated into the processing of those target expressions showing neutral. Thereafter, an integrated neutral expression would be perceived, or when re-entering into the representation, though the target expression was replaced by the mask, it would not cause as much confounding effect as on expressions showing conflict emotional content.

More interestingly, the recognition of happiness did not show any advantage in the backward masking task either. It accordingly implies that the recurrent processing of the representation of visual input is key to the happiness advantage. When recurrent processing was disrupted (i.e. backward masking task) or the processing of representation was no more critical (i.e. simple categorization task), no advantage was shown for the recognition of happiness. While possible reasons for happiness advantage have been previously discussed (Calvo & Nummenmaa, 2015), it is still not clear what mechanism is underlying this visual perceptual process. Therefore, in future studies, it is worth to consider whether the representation of a happy/smile face is formed differently from other expressions and whether the happiness representation could be better retained and make inferences about the emotional content in a more effective manner. It should be noted that in other backward masking studies, the happiness was recognised more accurately than other core emotions (e.g. Dimberg, Thunberg, & Elmehed, 2000; Maxwell & Davidson, 2004; Milders et al., 2008; Neath & Itier, 2014), though different task parameters were used for the current experiment, e.g. none of them included pain expressions. The reliability of this recurrent processing effect for happiness advantage is certainly worth to be considered in future studies.

In sum, the results of Experiment 6 suggest that the low-SF advantage stems from the temporal aspect of processing, which becomes most apparent during early stages of recognition. However, it is unclear whether the low-SF information is processed faster or earlier than high-SF information. This experiment was not set up to confirm this directly, so the stage at which the processing of low-SF information precedes high-SF information, and the point at which low-SF information would lose its processing advantage over high-SF remain unknown. In order to have a more comprehensive view of the time course of SF information processing, the next chapter, therefore, seeks to (1) consider the temporal dynamics of SF information at different stages of processing separately, i.e. the information extraction and the perceptual analysis, and (2) further examine the reliability of the findings of the current experiment.

Chapter 8 Experiment 7: The temporal dynamics of extraction and decoding of SF information in pain recognition

8.1 Introduction

As reported in Chapter 6 and 7, Experiment 5 and 6 examined the temporal feature of SF information processing in the recognition of pain expressions and compared with core emotions. These experiments found that low-SF information played a preliminary role in pain recognition (Chapter 6) and required less processing time for reliable recognition than high-SF information did (Chapter 7). This suggests that the low-SF advantage may indwell in the temporal aspect and benefit from the rapid processing when compared to high-SF information. As far as I am aware, this is the first time that the time course of SF information processing has been studied in the context of expression recognition, especially with reference to pain. Thus, one purpose of the current experiment (Experiment 8) is to examine the reliability of these findings. More importantly, as discussed in Chapter 7, it is not yet clear the point at which the processing of low-SF information precedes high-SF, and when low-SF information would lose its advantage. Therefore, this final experiment in my PhD thesis (Experiment 8) sought to explore the underlying dynamics of SF information processing at different stages of visual perception. I hope to be able to gain a more comprehensive understanding of how SF information is processed (i.e. temporal aspect) in order to make the recognition of pain possible, and how this compares with core emotions. The rationale for this, now follows.

Early perception relies on both extraction and decoding of specific visual information (Essen & Anderson, 1995; Roy et al., 2015; Smith & Merlusca, 2014). The extraction of information from a visual stimulus and the decoding of the visual input are two different visual processes that should be considered separately (Essen & Anderson, 1995). In Chapter 6 and 7, the temporal feature of SF information processing was considered in an integral manner, which consisted of both extraction and decoding processes. It is therefore not possible to conclude which mechanism is underpinning the temporal advantage of low-SF processing – information extraction, or decoding, or both of them. Thus, the aim of the current experiment was to investigate the extraction and the decoding of SF information as two distinct processes and examine in which process low-SF information exhibits an advantage over high-SF.

Two modified backward masking tasks were employed in this experiment, designed to separate the extraction and decoding process. To achieve this, target presentation durations and the target-mask SOAs were carefully manipulated. In Experiment 6, the allowed processing time (i.e. target-mask SOAs) were identical to the target presentation durations, in which the time required for information extraction and visual input decoding were not differentiated, and the two processes were studied as a whole. In the current experiment, the target-mask SOAs were no longer identical to the target presentation durations but consisted of two parts: the presentation duration of a target face, and a gap between the target offset and the mask onset (Figure 8-1). In this way, the presentation duration of targets allows observers to extract information from the image, and the SOA between the target and the mask determines the processing latencies required by decoding (i.e. perceptual analysis) of the visual input (Breitmeyer & Ogmen, 2000; Ogmen & Breitmeyer, 2006). To ensure the target presentation duration corresponds to the process of information extraction and allows minimal decoding processes, extremely low level of presentation durations (17 and 33 ms) were used (Hegdé, 2008; Ogmen & Breitmeyer, 2006; Ruiz-Soler & Beltran, 2006). Though this approach has rarely been applied to study facial expressions, it has been successfully used in studies on other visual stimuli, e.g. patterns, objects (Bachmann & Allik, 1976; Ogmen & Breitmeyer, 2006), and faces (Ruiz-Soler & Beltran, 2006).

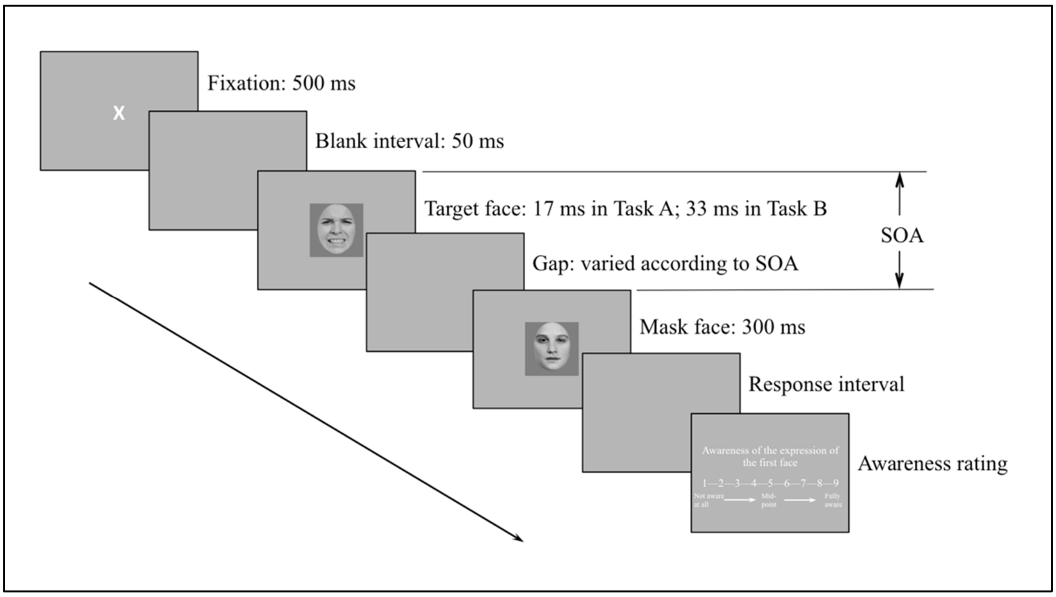

Figure 8-1 Details of trial procedure of the modified backward masking tasks

In the two tasks of this experiment, the presentation duration of the target stimulus was selected as 17 ms (Task A) and 33 ms (Task B), respectively. The extremely brief presentation durations were chosen to examine whether the characteristic information for the recognition of pain and core emotions could be adequately extracted from low-SF and high-SF within a given time period. In both of the tasks, a series of target-mask SOAs were selected (depending on the task, for details see section 8.2.4). The multiple SOAs within each task allowed the disruption of the decoding process of the target expression at various time points and examine the corresponding visual percept while keeping the target stimulus presentation duration unchanged. By comparing across the two tasks, it was able to directly examine the temporal dynamics of extraction and decoding of SF information in the recognition of facial expressions. It was hypothesised that low-SF information would require less time to extract and decode than high-SF in the recognition of pain expressions. The core expressions of fear, happiness, and neutral were also included in both of the tasks for comparison.

8.2 Methods

8.2.1 Design

Two modified backward masking tasks (i.e. Task A and Task B) were conducted, both of which used a mixed-groups design. In both tasks, the within-groups variables were the target-mask SOA (which varied depending on the task, see section 8.2.4 for details), the type of SF information (broad-SF vs. low-SF vs. high-SF), and expression (pain vs. fear vs. happiness vs. and neutral). A between-groups variable of participant sex (female vs. male) was included in both tasks. The dependent variable was recognition accuracy in both tasks.

8.2.2 Participants

Forty healthy adult participants (24 females and 16 males) were recruited, with a mean age of 28.12 (*SD* = 5.80). The participation eligibility and exclusion criteria for recruitment were the same as in previous experiments. Ethical approval was granted by the Department of Psychology Ethics Committee (Ref. 13-161) and the Department of Health Ethics Committee (Ref. EP 13/14 33a) of the University of Bath. Informed consent was obtained from all participants prior to taking part in the experiment. Participants were given £15 in return for completing both tasks.

8.2.3 Stimuli

The stimuli in both tasks were the same as those used in Chapter 6 and 7.

8.2.4 Tasks

Participants were asked to complete two backward masking tasks: Task A and Task B. The two tasks employed the same backward masking paradigm and used different parameters of the target presentation duration and the target-mask SOA.

In Task A, the presentation duration of all the target faces was 17 ms, and the target-mask SOAs were 17, 33, 67, 150, 300, and 1000 ms. When the SOA was 17 ms, the presentation duration of the target face was equal to the target-mask SOA, which means that the target face was replaced by the mask without a gap. For the rest of the SOAs (i.e. 33, 67, 150, 300, and 1000 ms), a gap of varied time lengths (i.e. 16/17, 50, 133, 283, and 983 ms, respectively) occurred between the target and the mask. In Task B, all the target faces were presented for 33 ms, and the target-mask SOAs were 33, 67, 150, 300, and 1000 ms. For the SOA of 33 ms, there was no gap between the target and the mask. For the SOAs of 67, 150, 300 and 1000 ms, a gap of varied time lengths (i.e. 33/34, 117, 267 and 967 ms) occurred between target and mask. Both tasks required participants to give two sets of responses: the judgement of the target face expression and the rating of the awareness of the expression. The largest SOA of 1000 ms was used in both tasks, as results from Experiment 6 (Chapter 7) demonstrate that adequate processing of high-SF expressions requires more than 300 ms, and previous studies indicate that some brain responses to emotional faces can take up to 1000 ms or longer from stimulus onset (Salmon, Fischer, Vighetto, & Mauguière, 2001; Sabatinelli et al., 2011).

Both tasks (A and B) followed a similar procedure to that used in Experiment 6 Backward masking task, including the same stimuli for the target and the mask. For details of the trial procedure, please refer to Figure 8-1. In Task A, each participant completed 1152 trials (i.e. 96 target stimuli, 6 different SOAs, each repeated twice) with a break after every 192 trials. In Task B, each participant completed 960 trials (i.e. 96 target stimuli, 5 different SOAs, each repeated twice) with a break after every 192 trials. The stimuli were presented in a random order in both tasks.

Practice sessions consisted of 10 trials preceded Task A and Task B. The target face stimuli in practice were randomly selected from the stimulus set of 96 face images for each participant.

8.2.5 Procedure

The order of the tasks was counterbalanced across participants. Given the length of time, participants completed the two tasks on two separate occasions (same time in two consecutive days).

8.2.6 Data preparation and analysis

In both tasks, the dependent variable was recognition accuracy, which was analysed following the signal detection theory. The estimated sensitivity (A_g) was calculated for both tasks following the same procedure outlined in Chapter 7 (Section 7.2.6: Backward masking task).

Data were firstly analysed for Task A (target presented for 17 ms) and Task B (target presented for 33 ms) separately to examine, with a fixed target presentation duration given, whether increase of target-mask SOA (i.e. processing time) would improve the accuracy of expression recognition by using different types of SF information. And then, I analysed the data of Task A and Task B jointly to examine the effect of presentation duration (i.e. 17 vs. 33 ms) on the recognition of facial expressions. Please note that the SOA of 17 ms was not included in this analysis, as this level was only available in Task A.

The models of mixed-group ANOVA are reported for each task in the Results section. Simple effects analyses were applied when significant interactions found. *Post hoc* analyses followed the same principles as described in Chapter 4.

8.3 Results

8.3.1 Task A

In this task, all the target faces were presented for 17 ms, and the target-mask SOAs were 17, 33, 67, 150, 300, and 1000 ms.

Three participants (one female and two males) did not complete Task A[13]. Data were screened for invalid responses made within 200 ms or after 2000 ms of the target stimulus onset (2.68% of all trials). For completeness, after removal of invalid trials, the simple hit rates were calculated and are reported in Table 8-1. The A_g was calculated for each participant. One participant (female) was removed due to low A_g for happiness and pain in multiple conditions, with *z*-scores lower than -3.29. A final sample of 36 participants (22 females and 14 males) was included for Task A. The data were approximately normally distributed (z-scores of skewness and kurtosis between -3.29 and 3.29), and approximately homogeneous (all Levene's *p*s > .05).

Mean and *SD* of the A_g for female and male participants in each condition are presented in Table 8-2. One sample *t*-tests (two-tailed) revealed that for all the

[13] These participants completed Task B first but did not manage to complete Task A for different reasons.

expressions presented by broad-SF and low-SF, the A_g was significantly above the discrimination threshold (0.75) when the SOA was 67, 150, 300, and 1000 ms (all *t*s > 2.35, *p*s < .05, *d*s > 0.39). For expressions presented by high-SF, the A_g was significantly below the discrimination threshold for all the SOAs (all *t*s < -4.48, *p*s < .001, *d*s < -0.74), which suggest that the presentation duration of 17 ms is enough to extract adequate high-SF information from face stimuli for expression recognition.

Table 8-1 Task A: The simple hit rate (%) for expressions at each SF level with each SOA for female and male participants.

	Female (n = 23)						Male (n = 14)					
	17 ms	33 ms	67 ms	150 ms	300 ms	1000 ms	17 ms	33 ms	67 ms	150 ms	300 ms	1000 ms
Fear												
Broad-SF	35.87	44.02	66.30	87.50	88.59	87.50	37.50	48.21	68.75	83.93	95.54	92.86
Low-SF	34.24	48.37	67.93	79.89	84.24	84.24	41.07	41.07	66.96	75.89	90.18	90.18
High-SF	8.15	11.96	14.35	19.57	19.57	26.09	8.04	8.93	10.71	13.39	18.75	16.96
Happiness												
Broad-SF	25.00	35.33	64.13	87.50	87.50	89.67	19.64	32.14	64.29	76.79	80.36	83.04
Low-SF	16.85	32.07	69.57	81.52	84.78	89.13	24.11	33.93	62.50	70.54	78.57	82.14
High-SF	14.13	15.22	21.74	33.15	34.24	34.24	6.25	12.50	8.93	17.86	25.00	25.89
Neutral												
Broad-SF	30.98	31.52	38.04	72.83	81.52	83.15	40.18	41.96	55.36	83.93	84.82	90.18
Low-SF	32.61	29.35	33.15	62.50	72.83	78.26	33.04	47.32	55.36	83.93	86.61	86.61
High-SF	60.33	52.72	55.98	57.07	53.26	58.15	71.43	65.18	63.39	60.71	59.82	65.18
Pain												
Broad-SF	33.15	54.89	65.76	78.80	82.07	82.61	38.39	58.93	79.46	85.71	86.61	86.61
Low-SF	40.22	44.57	66.85	78.80	83.70	78.26	30.36	49.11	81.25	83.04	86.61	85.71
High-SF	11.96	13.04	21.20	32.07	38.59	30.98	7.14	10.71	17.86	23.21	25.00	25.89

Table 8-2 Task A: Mean (*SD*) of the A_g for expressions at each SF level with each SOA for female and male participants.

	Female (n = 22)						Male (n = 14)					
	17 ms	33 ms	67 ms	150 ms	300 ms	1000 ms	17 ms	33 ms	67 ms	150 ms	300 ms	1000 ms
Fear												
Broad-SF	.578	.663	.810	.939	.931	.937	.606	.695	.856	.940	.959	.961
	(.118)	(.146)	(.160)	(.091)	(.066)	(.064)	(.120)	(.084)	(.149)	(.061)	(.048)	(.042)
Low-SF	.538	.683	.823	.891	.930	.929	.635	.612	.846	.869	.947	.945
	(.140)	(.128)	(.114)	(.102)	(.081)	(.057)	(.131)	(.121)	(.147)	(.109)	(.063)	(.051)
High-SF	.477	.500	.534	.610	.664	.662	.495	.508	.535	.517	.617	.590
	(.094)	(.099)	(.113)	(.152)	(.148)	(.134)	(.129)	(.068)	(.094)	(.102)	(.113)	(.149)
Happiness												
Broad-SF	.567	.633	.832	.943	.944	.951	.602	.710	.848	.893	.886	.919
	(.122)	(.148)	(.118)	(.073)	(.067)	(.058)	(.168)	(.136)	(.117)	(.109)	(.109)	(.108)
Low-SF	.561	.657	.835	.919	.928	.955	.609	.645	.843	.881	.905	.926
	(.106)	(.105)	(.146)	(.092)	(.069)	(.052)	(.113)	(.127)	(.106)	(.090)	(.105)	(.073)
High-SF	.514	.490	.505	.608	.614	.668	.467	.470	.468	.593	.597	.581
	(.086)	(.101)	(.094)	(.141)	(.174)	(.146)	(.128)	(.076)	(.111)	(.123)	(.093)	(.158)
Neutral												
Broad-SF	.620	.690	.776	.925	.939	.942	.660	.684	.838	.914	.910	.933
	(.123)	(.123)	(.136)	(.079)	(.042)	(.057)	(.147)	(.097)	(.109)	(.053)	(.075)	(.066)
Low-SF	.601	.644	.785	.884	.912	.930	.609	.674	.826	.915	.926	.943
	(.150)	(.113)	(.106)	(.082)	(.065)	(.053)	(.124)	(.159)	(.119)	(.060)	(.065)	(.073)
High-SF	.554	.508	.534	.629	.630	.627	.501	.531	.479	.527	.546	.581
	(.114)	(.123)	(.118)	(.120)	(.133)	(.157)	(.164)	(.181)	(.157)	(.137)	(.127)	(.191)
Pain												
Broad-SF	.524	.686	.807	.919	.931	.921	.606	.769	.883	.941	.967	.939
	(.123)	(.181)	(.191)	(.098)	(.069)	(.090)	(.149)	(.105)	(.143)	(.057)	(.064)	(.065)
Low-SF	.560	.598	.828	.895	.924	.929	.554	.686	.889	.901	.951	.913
	(.176)	(.133)	(.163)	(.094)	(.080)	(.067)	(.094)	(.106)	(.117)	(.112)	(.067)	(.078)
High-SF	.504	.458	.565	.606	.630	.588	.558	.487	.539	.581	.561	.544
	(.119)	(.108)	(.112)	(.143)	(.185)	(.159)	(.089)	(.107)	(.094)	(.122)	(.175)	(.216)

The data of A_g were entered into a 6 × 3 × 4 × 2 (SOA [17 ms, 33 ms, 67 ms, 150 ms, 300 ms, 1000 ms] × SF Information [broad-SF, low-SF, high-SF] × Expression [fear, happiness, neutral, pain] × Participant Sex [female, male]) mixed-groups ANOVA.

A significant main effect of SOA was revealed, $F(3.65, 123.97) = 252.85$, $p < .001$, $\eta^2_p = .88$. Participants' identification performance (A_g) increased along with the SOA continuously from 17 ms to 150 ms, where the increase of A_g was significant between each two adjacent SOAs (all ps < .001, ds > 0.85). However, from the SOA of 150 ms to 1000 ms, the A_g did not increase significantly (all ps > .06, ds < 0.50).

The main effect of SF information was significant, $F(1.47, 50.05) = 624.41$, $p < .001$, $\eta^2_p = .95$. The A_g for broad-SF and low-SF expressions was higher than that for high-SF expressions (both ps < .001, ds > 4.13), and the A_g for broad-SF was higher than that for low-SF ($p < .05$, $d = 0.56$). The main effect of expression type was not significant, $F(3, 102) = 0.36$, $p = .78$.

A significant interaction was found between SOA × SF Information (Figure 8-2), $F(4.95, 168.33) = 32.77$, $p < .001$, $\eta^2_p = .49$. Simple effects analyses examined the effect of SOA on each SF level, and the SF difference at each level of SOA, separately. The effect of SOA was significant within each SF level, all Fs > 7.59, ps < .001, η^2_ps > .55. For broad-SF, the A_g increased continuously along with the SOA from 17 ms to 150 ms (all ps < .001, ds > 0.81), but no significant increase from 150 ms to 1000 ms (all ps = 1.00). For low-SF, the A_g increased continuously from 17 ms to 300 ms (all ps < .05, ds > 0.55), but no significant difference between 300 ms and 1000 ms ($p = 1.00$). For high-SF, the A_g for SOAs of 17, 33, and 67 ms was lower than that for 150, 300, and 1000 ms (all ps < .01, ds > 0.71), but no other significant difference found (all ps > .39). Significant SF difference was found at each level of SOA, all Fs > 17.33, ps < .001, η^2_ps > .51. At all the SOA levels, the A_g for broad-SF and low-SF was higher than that for high-SF, all ps < .001, ds > 0.71). In addition, when the SOA was 150 ms, higher A_g was found for broad-SF than low-SF ($p < .05$, $d = 0.55$).

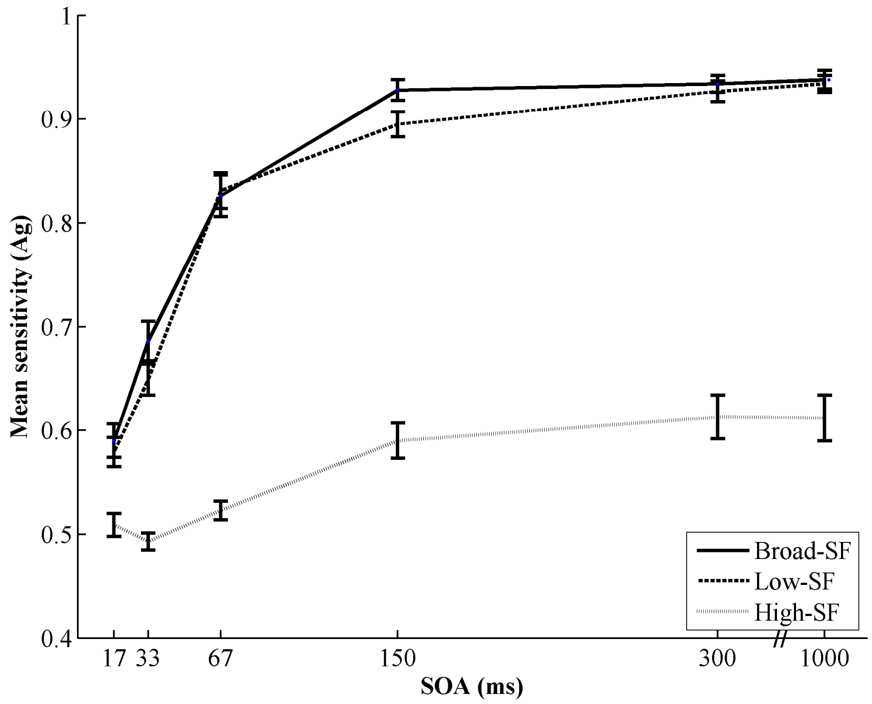

Figure 8-2 Mean sensitivity (A_g) to expressions presented by each type of SF information with each SOA in Task A (error bars represent *SEM*)

The interaction of SOA × Expression was also significant, however with small effect size, $F(8.61, 292.78) = 2.77$, $p < .05$, $\eta^2_p = .07$. Simple effects analyses were applied, and only marginal expression differences were revealed (see Figure 8-3). Significant expression differences were only found for SOAs of 300 ms and 1000 ms, both *F*s > 3.74, *p*s < .05, η^2_ps > .26. For SOA of 300 ms, fear was better identified than neutral ($p < .01$, $d = 0.51$); and for SOA of 1000 ms, fear was better identified than pain ($p < .01$, $d = 0.58$). Significant SOA effect was found for all the expressions, all *F*s > 51.95, *p*s < .001, η^2_ps > .89, and similar pattern revealed that A_g increased from 17 ms to 150 ms (all *ps* < .01, *ds* > 0.64). An additional significant increase was found for fear from 150 to 300 ms ($p < .01$, d = 0.71). For all the expressions, no significant difference was found between SOA of 300 and 1000 ms (all *p*s > .13).

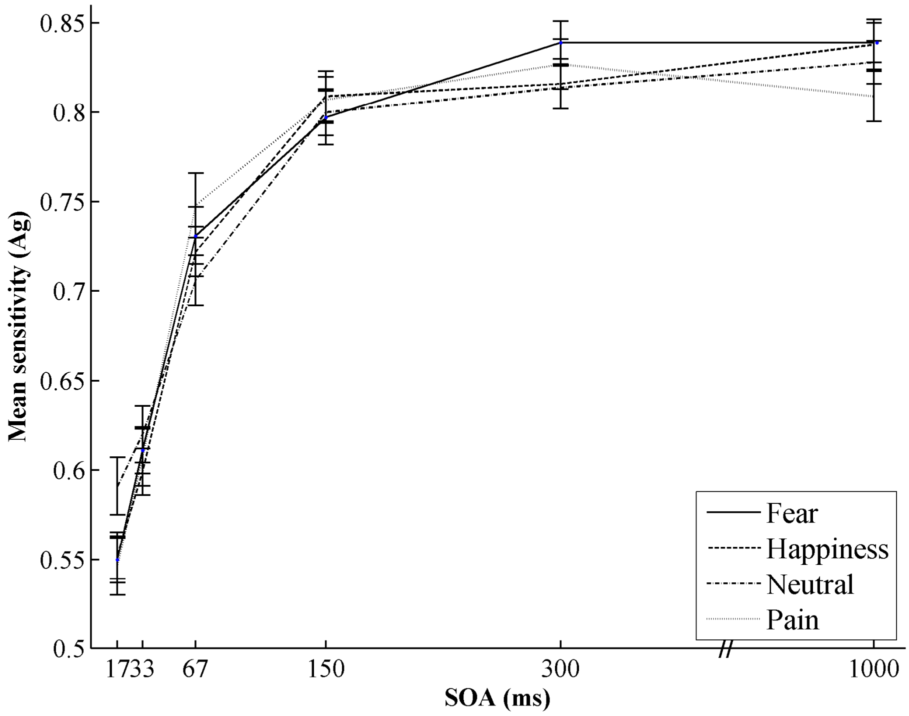

Figure 8-3 Mean sensitivity (A_g) to each expression with each SOA in Task A (error bars represent *SEM*)

In terms of sex differences, the main effect of participant sex was not significant, $F(1, 34) < 0.01$, $p = .99$, $\eta^2_p < .01$. A significant interaction was found for SOA × Participant Sex (Figure 8-4), with small effect size, $F(3.65, 123.97) = 2.75$, $p < .05$, $\eta^2_p = .07$. Significant effect of SOA was found for both female and male participants, both *F*s > 55.38, *p*s < .001, η^2_ps > .90. For females, the A_g increased along with the SOA from 17 to 150 ms (all *p*s < .01, *d*s > 0.80); whereas for males, the significant increase of A_g was from 33 to 150 ms (all *p*s < .01, *d*s > 0.94). However, no significant sex difference was found within any SOA level, all *F*s < 1.60, *p*s > .22.

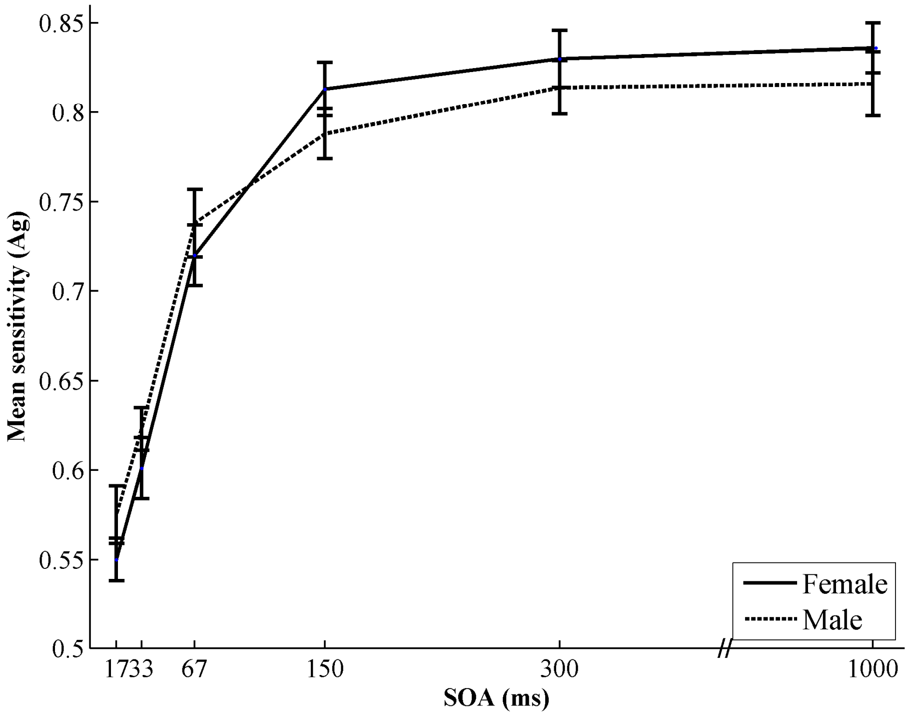

Figure 8-4 Female and male participants' mean sensitivity (A_g) to expressions with each SOA in Task A (error bars represent *SEM*).

A significant interaction was found for SF Information × Participant Sex (Figure 8-5), $F(1.47, 50.05) = 6.15$, $p < .01$, $\eta^2_p = .15$. Significant effect of SF information was found for both female and male participants (both Fs > 187.27, ps < .001, η^2_ps > .91), where similar pattern was revealed that both females and males had higher A_g for broad-SF and low-SF expressions than high-SF (all ps < .001, ds > 4.61), and no significant difference between broad-SF and low-SF (both ps > .08). Regarding sex difference, males had slightly higher A_g than females for broad-SF and low-SF expressions, and females had slightly higher A_g than males for high-SF expressions (see Figure 8-5), however, none of them reached significance level (all ps > .13). None of the other interactions was significant, all Fs < 2.50, ps > .08.

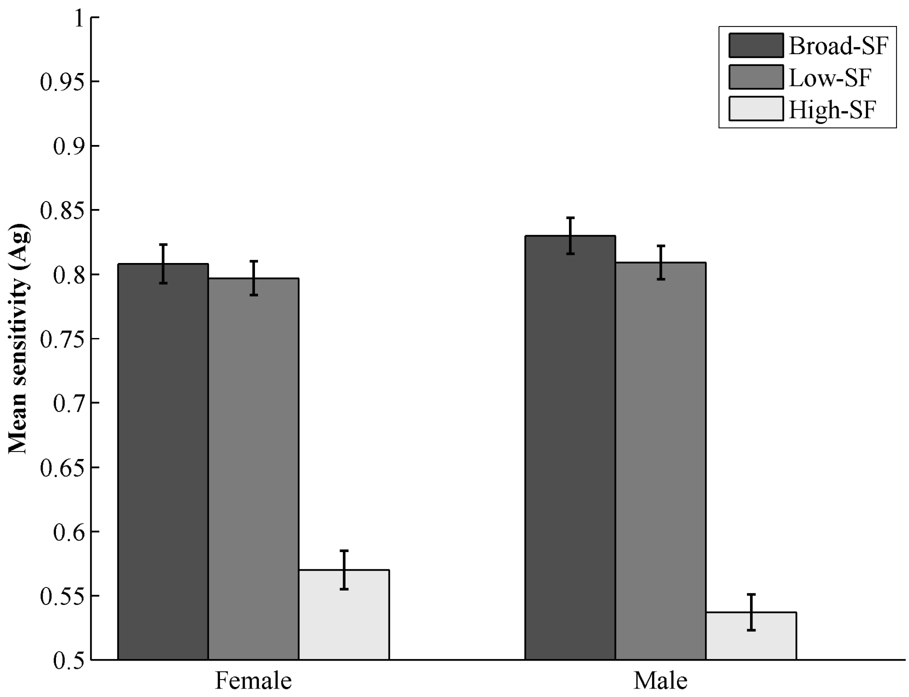

Figure 8-5 Female and male participants' mean sensitivity (A_g) to expressions presented by each type of SF information in Task A (error bars represent *SEM*).

Task A found that low-SF showed a temporal advantage over high-SF in terms of information extraction from visual stimuli. For low-SF expressions, the characteristic information could be extracted within 17 ms; whereas for high-SF, 17 ms was not enough to extract adequate perceptual information for further decoding/analysis, where an increase of processing time did not facilitate the perception of high-SF expressions. There were few differences between low-SF and broad-SF, which suggest that low-SF information is the main contribution at early stages of processing. Moreover, this pattern was found for both pain and core emotions.

8.3.2 Task B

In this task, all the target faces were presented for 33 ms, and the target-mask SOAs were 33, 67, 150, 300, and 1000 ms.

One participant (female) did not complete Task B. Data were screened for invalid responses made within 200 ms or after 2000 ms of the target stimulus onset (1.47% of all trials). For completeness, after removal of invalid trials, the simple hit rates were calculated and are reported in Table 8-3. The A_g was calculated for each participant. One participant[14] (female) was removed due to low A_g for happiness and pain in multiple conditions, with *z*-scores lower than -3.29. A final sample of 38 participants (22 females and 16 males) was included for Task B. The data were normally distributed (z-scores of skewness and kurtosis in between of -2.58 and 2.58), and approximately homogeneous (all Levene's *p*s > .05).

Mean and *SD* of the A_g for female and male participants in each condition are presented in Table 8-4. One sample *t*-tests (two-tailed) revealed that for all the expressions presented by broad-SF and low-SF, the A_g was significantly above the discrimination threshold (0.75) when the SOA was 67, 150, 300 and 1000 ms (all *t*s > 2.29, *p*s < .05, *d*s > 0.37). For expressions presented by high-SF, the A_g for happiness and neutral was above the threshold when the SOA was 300 and 1000 ms (all *t*s > 3.07, *p*s < .01, *d*s > 0.49), and the A_g for fear was above the threshold when the SOA was 1000 ms ($t(37) = 3.25$, $p < .01$, $d = 0.53$). However, for pain expressions, the A_g was not significantly higher than the threshold with any SOA (all *t*s < 0.16, *p*s > .86), which suggests that pain expressions may require longer viewing time for accurate recognitions than other core emotions when using high-SF information.

[14] The same participant as removed from Task A for the same reason.

Table 8-3 Task B: The simple hit rate (%) for expressions at each SF level with each SOA for female and male participants.

	Female (n = 23)					Male (n = 16)				
	33 ms	67 ms	150 ms	300 ms	1000 ms	33 ms	67 ms	150 ms	300 ms	1000 ms
Fear										
Broad-SF	52.17	77.17	86.96	87.50	97.28	51.56	67.19	85.94	89.06	93.75
Low-SF	56.52	71.74	88.04	88.04	89.13	53.91	73.44	87.50	88.28	85.94
High-SF	16.78	18.48	29.89	41.30	46.74	14.84	17.97	32.03	44.53	53.91
Happiness										
Broad-SF	37.50	71.74	90.22	88.59	90.76	32.81	65.63	78.91	83.59	85.16
Low-SF	36.41	64.13	87.50	90.22	89.67	33.59	54.69	72.66	81.25	82.81
High-SF	27.72	29.35	55.98	66.30	68.48	17.19	25.78	53.13	59.38	70.31
Neutral										
Broad-SF	40.22	54.35	73.91	82.61	85.33	46.88	69.53	93.75	92.97	90.63
Low-SF	38.59	52.72	73.91	80.98	81.52	43.75	65.63	81.25	91.41	89.06
High-SF	63.04	59.24	67.93	74.46	76.63	61.72	63.28	64.06	69.53	62.50
Pain										
Broad-SF	45.65	65.22	77.17	78.26	82.61	59.38	80.47	81.25	89.84	85.16
Low-SF	38.04	58.70	78.26	78.80	77.17	54.69	78.91	89.84	92.19	85.16
High-SF	22.83	24.46	44.02	50.54	50.54	22.66	28.91	57.03	51.56	54.69

Table 8-4 Task B: Mean (*SD*) of the A_g for expressions at each SF level with each SOA for female and male participants.

	Female (*n* = 22)					Male (*n* = 16)				
	33 ms	67 ms	150 ms	300 ms	1000 ms	33 ms	67 ms	150 ms	300 ms	1000 ms
Fear										
Broad-SF	.702 (.155)	.868 (.100)	.926 (.087)	.935 (.065)	.957 (.046)	.703 (.133)	.839 (.118)	.943 (.052)	.955 (.061)	.962 (.050)
Low-SF	.710 (.140)	.803 (.160)	.913 (.080)	.938 (.055)	.924 (.076)	.723 (.156)	.836 (.119)	.947 (.055)	.934 (.074)	.935 (.061)
High-SF	.550 (.117)	.648 (.126)	.718 (.142)	.776 (.115)	.818 (.120)	.571 (.116)	.552 (.102)	.717 (.094)	.769 (.141)	.812 (.132)
Happiness										
Broad-SF	.669 (.143)	.847 (.104)	.938 (.070)	.936 (.078)	.969 (.049)	.702 (.122)	.841 (.117)	.884 (.088)	.927 (.076)	.942 (.064)
Low-SF	.668 (.111)	.826 (.123)	.936 (.101)	.945 (.071)	.949 (.071)	.731 (.169)	.810 (.107)	.882 (.097)	.916 (.077)	.912 (.082)
High-SF	.557 (.119)	.531 (.132)	.721 (.140)	.827 (.112)	.829 (.095)	.548 (.138)	.618 (.120)	.735 (.156)	.795 (.129)	.814 (.128)
Neutral										
Broad-SF	.679 (.124)	.839 (.079)	.897 (.079)	.932 (.052)	.943 (.061)	.739 (.139)	.887 (.097)	.939 (.047)	.946 (.056)	.940 (.073)
Low-SF	.677 (.116)	.777 (.142)	.909 (.069)	.940 (.050)	.932 (.065)	.750 (.168)	.833 (.126)	.904 (.088)	.936 (.055)	.929 (.056)
High-SF	.599 (.112)	.630 (.119)	.731 (.152)	.813 (.094)	.834 (.109)	.555 (.148)	.627 (.074)	.745 (.119)	.809 (.099)	.789 (.156)
Pain										
Broad-SF	.660 (.147)	.841 (.123)	.926 (.085)	.933 (.075)	.951 (.075)	.745 (.172)	.851 (.137)	.918 (.089)	.962 (.073)	.940 (.068)
Low-SF	.621 (.145)	.776 (.180)	.911 (.090)	.913 (.082)	.912 (.101)	.750 (.124)	.862 (.137)	.953 (.055)	.935 (.089)	.945 (.063)
High-SF	.550 (.168)	.530 (.136)	.694 (.157)	.726 (.203)	.755 (.200)	.516 (.113)	.571 (.171)	.720 (.212)	.735 (.164)	.731 (.163)

The data of A_g were entered into a 5 × 3 × 4 × 2 (SOA [33 ms, 67 ms, 150 ms, 300 ms, 1000 ms] × SF Information [broad-SF, low-SF, high-SF] × Expression [fear, happiness, neutral, pain] × Participant Sex [female, male]) mixed-groups ANOVA.

A significant main effect of SOA was revealed, $F(2.29, 82.40) = 245.36$, $p < .001$, $\eta^2_p = .87$. The A_g increased continuously as the SOA increased from 33 ms to 300 ms (all *p*s < .001, *d*s > 1.11), but without significant difference between 300 ms and 1000 ms ($p = 1.00$).

The main effect of SF was significant, $F(1.31, 47.13) = 317.44$, $p < .001$, $\eta^2_p = .90$. The A_g for broad-SF and low-SF expressions was higher than that for high-SF expressions (both *p*s < .001, *d*s > 2.81), and higher A_g was found for broad-SF than low-SF ($p < .05$, $d = 0.52$). A significant main effect was found for expression type with small effect size, $F(2.46, 88.67) = 2.96$, $p < .05$, $\eta^2_p = .06$. However, after correction no significant difference was found between expressions (all *p*s > .12).

The interaction between SOA × SF Information was significant (Figure 8-6), $F(3.59, 129.26) = 7.61$, $p < .001$, $\eta^2_p = .17$. Simple effects analyses examined the effect of SOA on each type of SF information, and the SF difference at each level of SOA, separately. Significant effect of SOA was found for each type of SF information, all *F*s > 43.35, *p*s < .001, η^2_ps > .84. For both broad-SF and low-SF, the A_g increased along with the SOA continuously from 33 to 150 ms (all *p*s < .001, *d*s > 0.99), and no significant difference between 150 and 300 ms (both *p*s > .11) or 300 and 1000 ms (both *p*s = 1.00). In addition to this, the increase of A_g from the SOA of 150 ms to 1000 ms was significant for broad-SF expressions ($p < .001$, $d = 0.78$), but not for low-SF expressions ($p = 1.00$). For high-SF, the A_g increased along with the SOA from 67 to 300 ms (all *p*s < .001, *d*s > 1.03), but no significant increase between 33 and 67 ms, or 300 and 1000 ms (both *p*s > .27). Significant SF difference was found within each SOA level, all *F*s > 40.52, *p*s < .001, η^2_ps > .69. For all the SOA levels, the A_g for broad-SF and low-SF was higher than that for high-SF (all *p*s < .001, *d*s > 1.31). In addition, for SOA of 67 ms and 1000 ms, higher A_g was found for broad-SF than low-SF (both *p*s < .05, *d*s > 0.45).

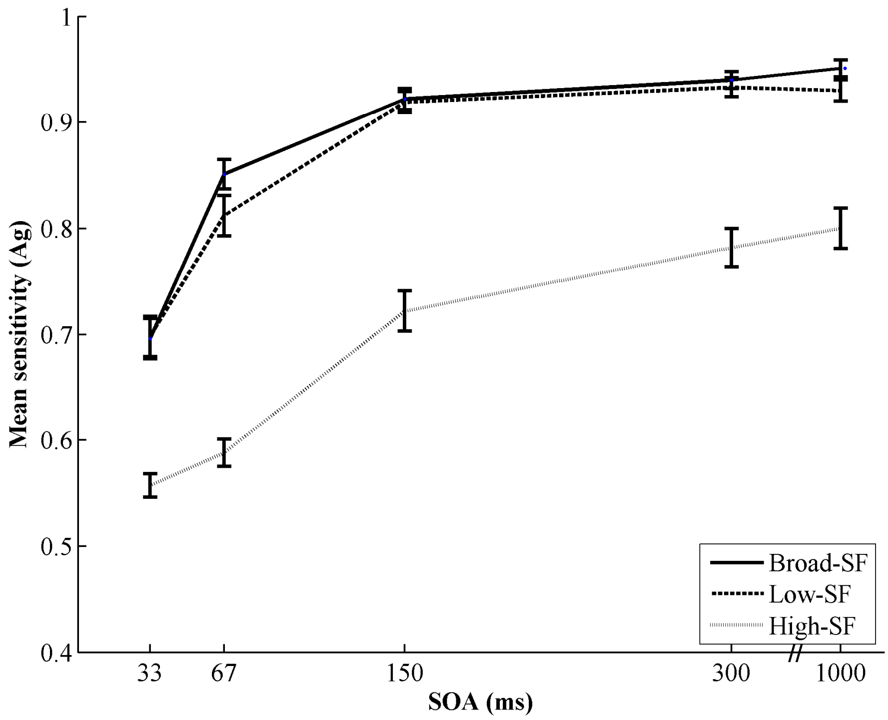

Figure 8-6 Mean sensitivity for expressions presented by each type of SF information with each SOA in Task B (error bars represent *SEM*).

A significant interaction was found between SF information and expression (Figure 8-7), $F(3.95, 142.31) = 5.54$, $p < .001$, $\eta^2_p = .13$. Significant effect of SF information was found for each expression, all Fs > 94.60, ps < .001, η^2_ps > .84. Similar pattern was revealed for all the expressions that the A_g for broad-SF and low-SF was higher than that for high-SF (all ps < .001, ds > 2.03), but no significant difference between broad-SF and low-SF (all ps > .08). Significant effect of expression was found for high-SF only, $F(3, 34) = 4.74$, $p < .01$, $\eta^2_p = .29$, where the A_g for neutral and happiness was higher than that for pain (both ps < .05, ds > 0.48), and a marginal difference was found between fear and pain ($p = .05$, $d = 0.42$).

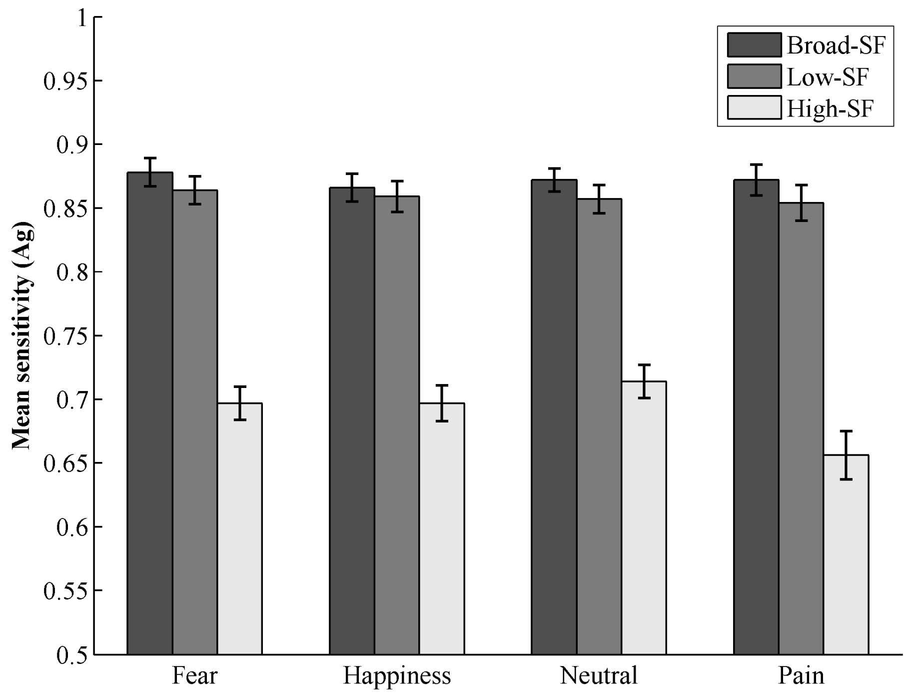

Figure 8-7 Mean sensitivity (A_g) for fear, happiness, neutral and pain at each SF level (error bars represent *SEM*).

In terms of sex difference, the main effect of participant sex was not significant, $F(1, 36) = 0.20$, $p = .66$. None of the other interactions was significant, all Fs < 2.05, ps > .12, η^2_ps < .06.

The results of Task B showed that low-SF information extracted within 33 ms could be efficiently decoded for reliable expression recognition within 150 ms. However, 33 ms was not quite enough to extract adequate high-SF information for reliable pain recognition. The decoding of high-SF information required more time (e.g. 1000 ms) than low-SF information did (e.g. 67 ms) to reach a comparable level of identification performance (e.g. $A_g = 0.8$). Though this pattern was found for both pain and core emotions, in this task pain was recognised less accurately than emotional expressions when presented by high-SF information.

8.3.3 Joint analysis of Task A and B

Final data for this analysis were from a sample of 36 participants (22 females and 14 males; Task A and B combined). The data of A_g were entered into a 2 × 5 × 3 × 4 × 2 (Target Presentation Duration [17 ms, 33 ms] × SOA [33 ms, 67 ms, 150 ms, 300 ms, 1000 ms] × SF Information [broad-SF, low-SF, high-SF] × Expression [fear, happiness, neutral, pain] × Participant Sex [female, male]) mixed-groups ANOVAs. Please note that the SOA of 17 ms was not included in this analysis, as this level was only available in Task A. This analysis focused on the effect of target presentation duration, thus simple effects analyses and *post hoc* comparisons were only applied when significant main effect or interactions were found for the target presentation duration, as the effects of other variables were analysed separately for Task A and Task B and reported in detail in previous sections.

Statistical analysis revealed a significant main effect of target presentation duration, $F(1, 34) = 65.26$, $p < .001$, $\eta^2_p = .66$, where the A_g was higher for expressions presented for 33 ms than those presented for 17 ms.

Significant main effects were also found for SOA and SF information (both Fs > 315.29, ps < .001, η^2_ps > .90), but not expression type ($F(3, 102) = 0.80$, $p = .50$).

The interaction between Target Presentation Duration × SOA was significant (see Figure 8-8), $F(2.72, 92.41) = 3.83$, $p < .05$, $\eta^2_p = .10$. Significant effects of target presentation duration were found for all the SOA levels (all Fs > 4.87, ps < .05, η^2_ps > .12), where higher A_g was found for target expressions presented for 33 ms than 17 ms. The effect of SOA was significant for presentation duration of 17 ms and 33 ms, both Fs > 85.51, ps < .001, η^2_ps > .91, however, different patterns revealed (see section 8.3.1 and 8.3.2 for analyses of the effect of SOA in Task A and Task B respectively).

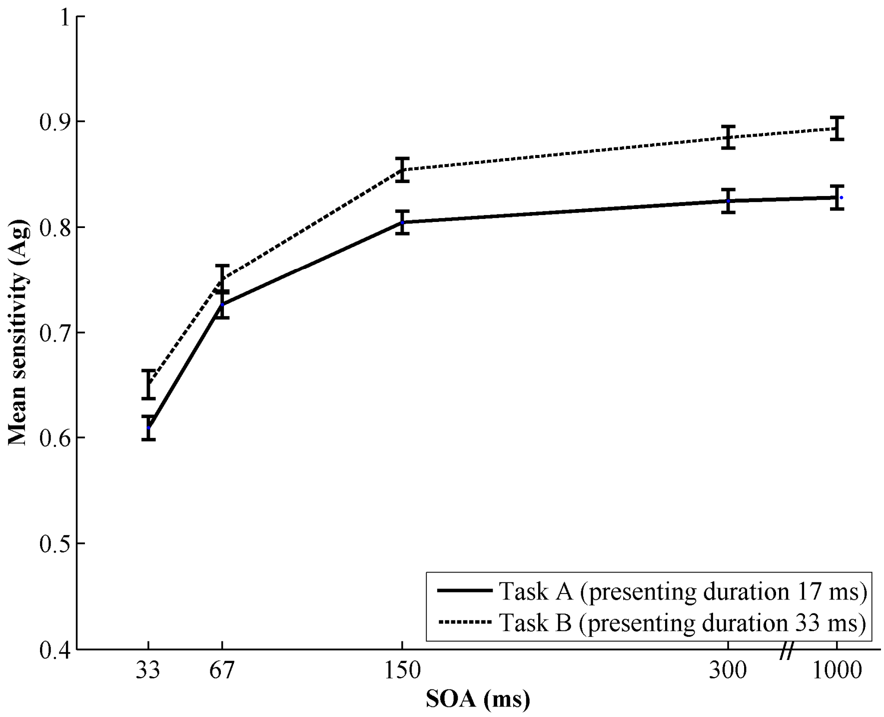

Figure 8-8 Mean sensitivity (A_g) to expressions presented for 17 ms (Task A) and 33 ms (Task B) with each SOA (error bars represent *SEM*).

The interaction of Target Presentation Duration × SF Information was significant (Figure 8-9), $F(1.59, 54.01) = 78.97$, $p < .001$, $\eta^2_p = .70$. A significant effect of presentation duration was found for high-SF expressions only ($F(1, 34) = 123.72$, $p < .001$, $\eta^2_p = .78$), where higher A_g was found for those presented for 33 ms compared to 17 ms. The effect of target presentation duration was not significant for broad-SF or low-SF, both Fs < 3.44, ps > .08.

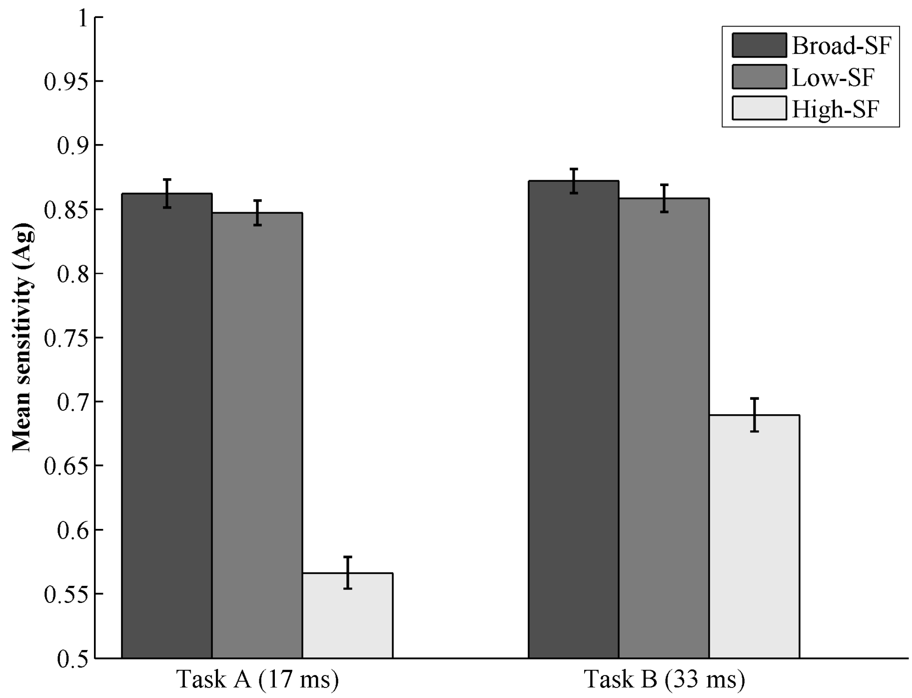

Figure 8-9 Mean sensitivity (A_g) to expressions presented for 17 ms (Task A) and 33 ms (Task B) by each type of SF information (error bars represent *SEM*).

The interaction of Target Presentation Duration × SOA × SF Information was significant (Figure 8-10), $F(5.94, 201.97) = 11.35$, $p < .001$, $\eta^2_p = .25$. Separate analyses were then applied to examine the effect of Target Presentation Duration × SOA for each type of SF information. For broad-SF and low-SF information, the effect was not significant, both *F*s < 2.03, *p*s > .16, η^2_ps < .06. For high-SF information, the interaction between presentation duration and SOA was significant, $F(4, 140) = 14.12$, $p < .001$, $\eta^2_p = .29$. For high-SF, the significant effect of presentation duration was found at each SOA level (*F*s > 13.40, *p*s < .001, η^2_ps > .27), where higher A_g was found for high-SF expressions presented for 33 ms compared to those presented for 17 ms (all *p*s < .001, *d*s > 0.78).

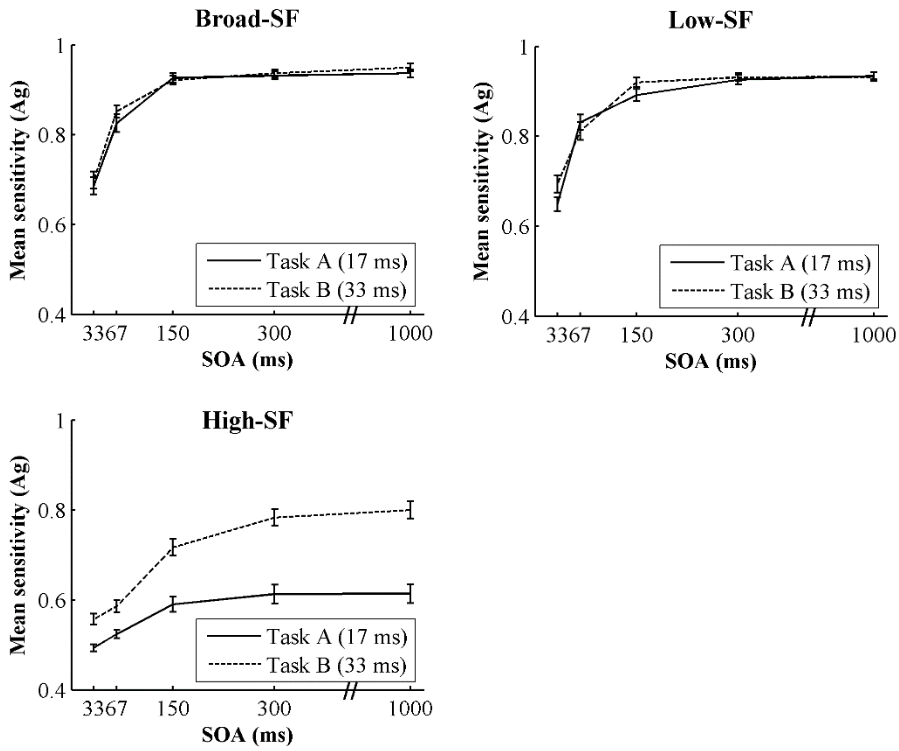

Figure 8-10 Mean sensitivity (A_g) to expressions presented for 17 ms (Task A) and 33 ms (Task B) by each type of SF information with each SOA (error bars represent *SEM*)

The interaction between target presentation duration and expression was significant (Figure 8-11), $F(3, 102) = 4.09$, $p < .01$, $\eta^2_p = .11$. Significant effect of target presentation duration was found for all the expressions, where expressions presented for 33 ms had higher A_g than those presented for 17 ms. However, smaller effect size was found for pain expressions ($F(1, 34) = 12.12$, $p < .01$, $\eta^2_p = .26$) than core emotions (all *F*s > 46.44, *p*s < .001, η^2_ps > .57). The effect of expression type was not significant for both presentation durations, both *F*s < 1.68, *p*s > .19.

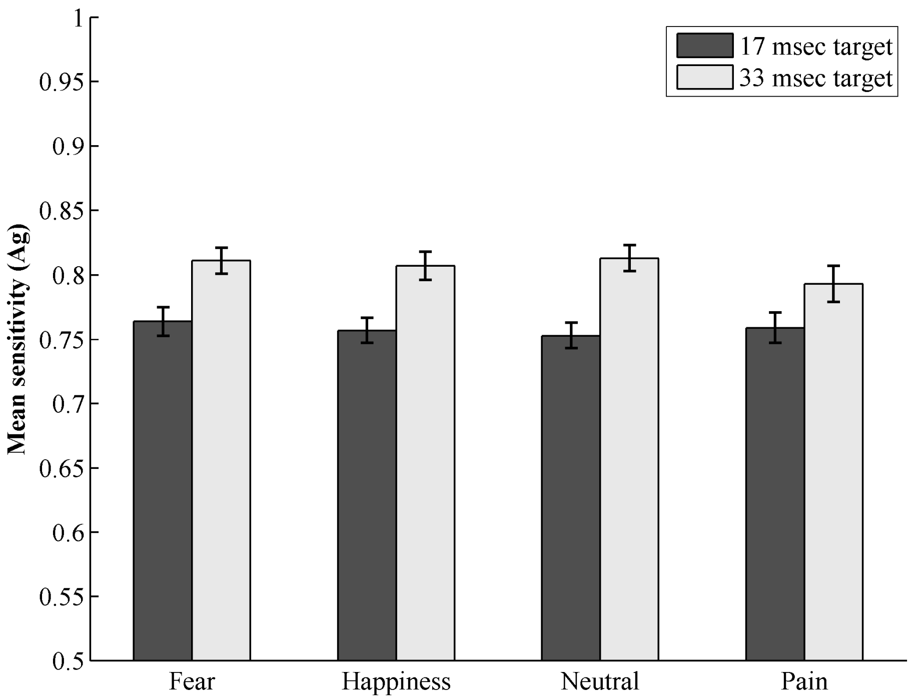

Figure 8-11 Mean sensitivity (A_g) to each expression presented for 17 ms (Task A) and 33 ms (Task B) (error bars represent *SEM*).

In terms of sex difference, the main effect was not significant, $F(1, 34) < 0.01$, $p = .94$; and none of the interactions was significant, all *F*s < 1.67, *p*s > .13.

The results of joint analysis of Task A and Task B suggest that for expression recognition, the extraction of information from low-SF elements seemed to be faster than that from high-SF elements, where low-SF information could be extracted within 17 ms and high-SF needed more than 33 ms. Although this pattern was found for both pain and core emotions, one expression difference was found for high-SF information that high-SF pain required longer presentation than core emotions.

8.4 Discussion

The current experiment investigated the temporal dynamics of SF processing at different stages (i.e. extraction and decoding) in the recognition of pain and core emotions. As expected, low-SF information required less time to be extracted and decoded than high-SF information in the recognition of facial expressions, including pain. It is consistent with the findings of Chapter 6 and 7 that low-SF information played a preliminary role at early stages of recognition, which again suggests that the low-SF advantage is emanated from the temporal aspect of processing.

More importantly, this experiment confirmed that the asynchrony between low-SF and high-SF information processing originated from a very early stage of information extraction. The extraction of characteristic information from low-SF elements was extremely efficient and required about 17 ms presentation duration or even possibility less, whereas adequate extraction from high-SF elements was slower. Though the adequate presentation duration for high-SF expressions did not emerge in this experiment, it was discovered that 33 ms might not be enough to accumulate adequate fine-detailed information (i.e. high-SF) to solve the expression recognition task. In this case, increasing of processing duration would not facilitate the perception. This experiment also shows that the processing/decoding of low-SF information is not only faster in duration but also precedes the processing of high-SF information – the decoding of high-SF visual input might be delayed due to the slow information extraction process. Moreover, these findings also suggest that the information extraction is a fundamental step for visual percept. When inadequate information is extracted from visual stimuli, further decoding process would not be able to produce an accurate interpretation.

Again, few differences were found between broad-SF and low-SF information in the current experiment, which suggests that the fast perception of pain and core emotional expressions seemed to rely on the processing of coarse low-SF information, even when intact information was available. On the other hand, it seemed that high-SF information might not make a significant contribution to the early processing of facial expressions. If so, then one question to ask is whether we actually need the fine detailed information at all for fast expression detection? This point will be returned to in the general discussion (Chapter 9).

Another key question addressed here is whether facial expressions of pain are processed in a similar way to core emotions. The presentation duration and processing time required for pain recognition in the current experiment were found to be similar compared to emotional expressions (i.e. fear, happiness, and neutral), though high-SF pain seemed to need longer presentation than core emotions. From the perspective of perceptual information analysis, pain and these core emotions may share similar visual perceptual properties, in terms of the extraction and decoding of perceptual (SF) information.

However, it should be noted that the increased presentation duration from 17 ms to 33 ms facilitated the recognition of pain presented by high-SF to a smaller extent when compared to core emotions. Though the mechanisms underlying this are unclear, there are several possible angles could be taken to consider this further. First, the characteristic features that encode pain may be more difficult to detect from high-SF information, and the recognition of pain relies more on the information conveyed by low-SF elements than core emotions, in particular at early stages. Another possibility is that pain expressions function to elicit helping behaviours and/or alert other people about potential dangers, both of which require behavioural responses following the recognition of pain, where fine-detailed information searching and more sophisticated processing are required for further decision making than the processing of emotional expressions. This distinct processing feature of pain expressions is certainly worth investigating further in future research.

In this experiment, the recognition of happiness did not show any advantage, which is in line with Experiment 6 that when the recurrent processing was disrupted, the happiness advantage was accordingly eliminated. Moreover, the current experiment compared the percept of expressions in terms of both information extraction and decoding, where happiness expressions were not perceived advantageously in either of the processes. These findings indicate that the characteristic information of happiness might not be more salient or extracted more efficiently than other expressions. Again the recurrent processing of the representation of facial expressions could be the key to happiness advantage.

Similar to previous experiments, there was little evidence for sex differences. However, men and women exhibited different tendencies (though not significant) in the processing of low-SF and high-SF information. For example, males seemed to be good at using low-SF information, whereas females showed potential advantages in using high-SF information. While very subtle effects, it is worth to examine further whether women and men process SF information differently in facial expressions perception.

Taking together, this experiment demonstrates that the asynchrony of low-SF and high-SF information processing starts from a very early stage of information extraction – the decoding of high-SF information is largely delayed by slow information extraction when compared to low-SF information. The processing of low-SF information is not only faster in duration but also precedes the processing of high-SF information, and this conclusion supports the coarse-to-fine hypothesis that the large-scale overall quality takes precedence over the fine details in expression recognition of pain and core emotions.

Chapter 9 General discussion

This final chapter concludes this thesis by firstly reviewing the research questions and summarising the key findings of each experiment, which are then discussed in the broader context of how we might decode of facial expressions of pain. Limitations in the experiments will be acknowledged along with possible solutions. Finally, several future directions are provided.

9.1 Summary of the research question and key findings

The aim of this thesis was to provide a visuoperceptual account (Irani, 2011) of how we recognise facial expressions of pain. Previous studies confirmed that individuals' experience of pain could be identified from their facial expressions in an accurate and efficient manner (Kappesser & Williams, 2008; Reicherts et al., 2012; Simon et al., 2008), even under challenging visual conditions (Czekala et al., 2015; Roy et al., 2015). The sensitivity to facial pain expressions has obvious survival value and suggests a reliable and efficient decoding process involved. Yet, little is known about how facial expressions are processed by observers, and what information is used, to make the recognition of pain possible. To account for this, the current thesis considered facial expressions as a type of visual stimulus that we encounter on a daily basis, and investigated possible mechanisms that underpin the recognition of pain expressions from the perspective of perceptual information analysis.

The novelty of this thesis lies in the approach I choose to investigate pain expression recognition, which was to consider spatial frequency information. Spatial frequency (SF) information is a type of fundamental perceptual information that determines the appearance of a visual display. Different SFs encode different characteristic information about any visual image, including a face. For a facial expression, low-SF information conveys the large-scale facial configuration and structural changes, whereas high-SF information depicts the fine details of facial features (De Cesarei & Codispoti, 2013; Hole & Bourne, 2010; Rolls et al., 1985;

Rolls, 2011; Ruiz-Soler & Beltran, 2006). In order to understand how we recognise pain expressions in terms of SF analysis, a series of experiments were therefore conducted within this thesis to primarily investigate the *role* of low-SF and high-SF information in the recognition of pain expressions (Experiment 1–4), and then the *temporal feature* of low-SF and high-SF information processing in pain recognition (Experiment 5–7). Along with the primary research questions, two secondary questions were raised and explored: (1) whether pain expressions were processed in a similar way to core emotions; and (2) whether observers' sex would play a role in the recognition. A summary of the research questions for each experiment can be found in Chapter 2 Table 2-1.

In this section, I will briefly return to the key results of each experiment before bringing them together and discussing the wider implications.

In this thesis, I firstly investigated the role of low-SF and high-SF information in the recognition of facial expressions of pain. Although pain expressions could be reliably recognised with either low-SF or high-SF information available, the low-SF information made a more prominent contribution (Experiment 1). Moreover, when both low-SF and high-SF information were available at the same time (i.e. hybrid faces), observers were biased towards using low-SF over high-SF information for pain recognition, in particular when face stimuli presented briefly (Experiment 2–4). These findings suggest that a more efficient process of pain recognition may be preferentially based on low-SF information, which is more characteristics for pain expressions and perceptually preferred by observers.

Then, I moved on to investigate the temporal feature of SF information processing to directly examine whether the recognition of pain would be more efficient using low-SF than high-SF information. A temporal advantage of low-SF information was demonstrated – when the presentation duration was brief, pain expressions presented by low-SF information were recognised more accurately than those presented by high-SF information (Experiment 5). Moreover, when no time constraint was applied (i.e. presentation duration and response time are unconstrained but controlled by participants), low-SF and high-SF information were equally informative for pain expressions (Experiment 6 – Simple categorization task), which further supports that the advantage of low-SF information may indwell in the temporal aspect of processing. By using a backward masking paradigm, direct evidence was found to demonstrate the temporal advantage of low-SF information processing – pain expressions presented by low-SF required approx. 150 ms for reliable recognitions, whereas high-SF pain expressions needed more than 300 ms (Experiment 6 – Backward masking task). Further to this, I investigated the temporal dynamics of SF information at different stages of processing, i.e. extracting information from visual stimuli and decoding of the visual input. The investigation revealed that low-SF information was not only decoded or perceptually analysed more rapidly, but also required less time to extract from visual stimuli than high-SF information. Thus, the temporal advantage of low-SF processing originated from a very early stage of information extraction, which demonstrates that the processing of low-SF information is not only faster in duration but also preceded the processing of high-SF information (Experiment 7).

Altogether, what these studies seem to suggest is that when we recognise a pain expression, the coarse low-SF information seems to play a key role in the fast detection or at early stages of processing. The early stage processing provides a preliminary understanding of the pain expressions that can be progressively refined when the fine-detailed high-SF information is integrated at a later stage.

Regarding the secondary research questions within this thesis, this pattern described above was found not only for the recognition of pain expressions, but also the core emotions investigated. This suggests that expressions of pain and core emotions share similar visual perceptual properties and processing time course. As will be considered below, the uniqueness or otherwise of pain from other facial expressions seems limited. In terms of possible sex differences, throughout the experiments in this thesis, few sex differences were found in the recognition of pain and core emotions by using SF information. This indicates that if the decoding of pain expressions by men and women does exist (and there is a debate as to whether this is actually the case), then this may bifurcate at a relatively later stage of processing, possibly happening after the perceptual information analysis.

9.2 Discussion of the findings and implications

So, what can we learn from the results presented in this thesis? I will try to explore this by discussing the key findings and implications from two main aspects: (1) how do we recognise facial expressions of pain, and (2) is the facial expression recognition of pain different from core emotions? Some other interesting findings of a possible "happiness advantage" and observers' sex differences are also discussed.

9.2.1 *How do we recognise facial expressions of pain?*

One of the most important findings of this thesis is the prominence of low-SF information in the recognition of pain expressions. While both low-SF and high-SF information contributes to our understanding of facial pain expressions, the large-scale coarse information conveyed by low-SF elements is particularly more "useful" for efficient recognitions when compared to the fine-detailed facial features conveyed by high-SF (Experiment 1 and 5–7). These results reveal for the first time that what is key to our recognition of pain from facial expressions – the large-scale overall quality conveyed by facial structural changes.

Detection of others' pain through facial expressions is usually believed to rely heavily on the analysis of facial movements of brow lowering, tightening and closing of the eyelids, nose wrinkling, and upper lip raising (Boucher, 1969; Corbett et al., 2014; Davies & Hoffman, 2002; Hale & Hadjistavropoulos, 1997; Kappesser & Williams, 2002; Kunz, 2015; Kunz & Lautenbacher, 2014, 2015; Patrick et al., 1986; Roy et al., 2015; Williams, 2002). These musculature movements are core to the decoding of pain expressions, as they are specific to facial expressions accompanying pain experiences, distinct from other non-noxious emotional expressions, and able to account for a substantial amount of variance in observers' judgement of pain from facial expressions (Craig, 1992; Craig & Patrick, 1985; LeResche, 1982; LeResche & Dworkin, 1984; Prkachin, 1992b; Prkachin & Solomon, 2009).

However, one question that could be asked is whether the core movements for pain faces are effectively used and analysed by observers to recognise pain from facial expressions? If not, then how facial expressions are processed and what information is used by observers to make the recognition of pain possible. As discussed in Chapter 1, analysis of facial actions is very time-consuming and requires extensive training of using the FACS. It is known that naïve observers without knowledge of FACS are able to differentiate pain from non-noxious emotional expressions in a reliable (Kappesser & Williams, 2008; Reicherts et al., 2012; Simon et al., 2008) and efficient way (Czekala et al., 2015), which suggests that strategies different from facial action analysis may be adopted. The findings of this thesis inferred that when detecting whether a facial expression is showing pain or other non-noxious expressions, observers preferentially perceive the overall expression conveyed by the large-scale structural changes of the face as a whole rather than analysing a series of facial actions.

In this thesis, observers, without previous knowledge of the core action units for pain, could accurately recognise a facial expression of pain within 150 ms, even when they only viewed the face from a fleeting glance of 17 ms (Experiment 6 and 7). Within such a short period of time in hundreds of milliseconds, it is not plausible for naïve observers to accomplish the analysis of facial actions, or search for the facial cues. More importantly, the facial expressions that were accurately recognised on this ultra-fast time scale were presented at a degraded viewing condition with coarse information conveyed by very low SFs only. In this condition, the fine details of facial features and musculature movements that conveyed by relatively high SFs were largely diminished, for example, the edge of eyelids or lips, and wrinkles and creases around the nose, which considered core to pain expressions were visually unavailable. On the contrary, when fine-detailed information was emphasised by using high-SF, observers required longer viewing time (i.e. > 33 ms) and processing time (i.e. > 300 ms) but produced less accurate recognitions (Experiment 6 and 7).

Neural mechanisms may have also evolved to facilitate this low-SF advantage. At an early stage of visual perception, our visual system extracts information from a visual stimulus in terms of SF components (Bullier, 2001; De Valois & De Valois, 1980; Shapley & Lennie, 1985) and analyses the visual input on multiple SF scales (Bar, 2004; Kauffmann et al., 2014; Skottun, 2015). The low-

SF and high-SF visual inputs are preferentially transmitted through two distinct visual pathways, namely magnocellular and parvocellular pathway respectively, in different conduction velocities that the magnocellular pathway (low-SF) is relatively faster than the parvocellular pathway (high-SF; Shapley & Lennie, 1985; Skottun & Skoyles, 2008a, 2008b). Furthermore, a subcortical visual processing pathway has been proposed to transfer coarsely degraded (low-SF) information to the amygdala (Méndez-Bértolo et al., 2016; Vuilleumier et al., 2003), which has previously been found to play a pivotal role in processing social cues and threatening facial expressions (Sander et al., 2003), and in the judgment of others suffering (Ochsner et al., 2008; Simon et al., 2006; Presseau et al., 2012).

Another implication that could be drawn from this thesis is that decoding of facial expressions of pain is not onefold, but consists of multiple processes that function differently. The judgement of authenticity, estimation of severity, and differentiation of pain from non-noxious emotions have all been extensively studied from the perspective of observers' decoding of facial expressions of pain (see Chapter 1 for details). The core facial action units were found to account for more than half of the variance in observers' judgement of others' pain (Breau et al., 2001; Goodenough, Champion, Laubreaux, Tabah, & Kampel, 1998; McGrath, Rosmus, Canfield, Campbell, & Hennigar, 1998) and reveal the authenticity of pain expressions (Hadjistavropoulos et al., 1996; Hill & Craig, 2002, 2004; Poole & Craig, 1992). However, according to this thesis, observers' differentiation of pain from non-noxious expressions relied heavily on the large-scale structural information of the expression rather than the fine-detailed facial actions. These findings indicate that (1) there may be dissociations between the facial cues encoding the characteristic quality of pain and the severity and authenticity, and (2) recognition of affective content and estimation of severity or intensity may be functionally independent of each other, involve different processing mechanisms, and may also happen at different stages of decoding of facial expressions of pain. This point will be further addressed in the section of 9.4 for future direction.

9.2.2 *Expression recognition: pain vs. core emotions*

Another key question addressed in this thesis is whether facial expressions of pain are processed in a similar way to core emotions or not. From the perspective of perceptual (i.e. SF) information analysis, this thesis found that recognition of pain and core emotions (i.e. fear, happiness, and neutral) shares very similar visual perceptual properties, as well as processing time course at very early stages (Experiment 2–7). It is known that the recognition accuracy and perceived valence and arousal level of pain expressions are comparable to those of the core emotional expressions (Czekala et al., 2015; Kappesser & Williams, 2002; Reicherts et al., 2012; Roy et al., 2015; Simon et al., 2008; Simon et al., 2006). The findings of this thesis extend our knowledge about pain compared to emotional expressions that the visual cues observers used to perceive the different characteristics of pain and emotions are conveyed by the same perceptual information – coarse low-SF information, which is processed similarly at a basic visuoperceptual level in the recognition of pain and core emotions. This may be because emotion is an essential component of pain and consists multiple pain-related negative affect, such as unpleasantness, distress, and fear of pain (Mounce, Keogh, & Eccleston, 2010). Whilst these pain-related emotions and the core emotions may possess different affective qualities, the characteristic information of these emotions may be encoded by the same type of perceptual information in facial expressions. If true, it seems that when recognising pain, we may preferentially process or perceive the emotional/affective qualities of pain, which are distinct from other negative core emotions and enough to produce accurate recognition of pain. However, this is speculative and worth considering in future studies.

It has been argued that whether pain expressions should be counted for or considered as one of the core expressions, and it turns out that in most cases, pain is neglected in the literature on emotional/affective expressions. Although this thesis does not seem to provide direct evidence that pain is one of the core expressions, it does provide a means of bridging the gap between facial pain expressions and core emotional expressions by showing that our visual perceptual system processes expressions of pain the same way that it does core emotions at very early stages of processing. There was one exception found in Experiment 1 that the low-SF advantage was found for pain and only one other type of expression, namely disgust, in the identification task, but not for other expressions. This could be because different task parameters were used in Experiment 1, and different types of processing involved. Please refer to Chapter 6 for a detailed discussion on this point.

9.2.3 *"Happiness advantage"*

In emotion recognition studies, happiness often shows an advantage over other expressions in terms of better recognition accuracy and shorter response time (Calvo & Nummenmaa, 2015). However, in this thesis the "happiness advantage" was only observed in certain conditions, where face stimuli were presented for a limited duration and not backwardly masked (Experiment 1 and 5). On the contrary, in experiments that had face stimuli backwardly masked (Experiment 6 Backward masking task, and Experiment 7) or no time constraint was applied (Experiment 6 Simple categorization task), recognition of happiness did not show an advantage over other expressions. As discussed in Chapter 7, this suggests that what is key to the perception of happiness expression is recurrent processing of the representation of the visual input, which plays a key role in visual percept when limited viewing time is available and could be easily disrupted by backward masking. Thus, it is possible that a representation of a happy/smile face could be formed differently from other expressions, and/or the happiness representation could be better retained in short term memory and used to make inferences about the emotional content. While possible reasons for happiness advantage have been previously discussed (Calvo & Nummenmaa, 2015), it is still not clear what mechanism is underlying this recognition process. It may be worth to investigate possible mechanisms underpinning the happiness advantage from a perspective of perceptual information processing. It should be noted that in other people's backward masking studies, happiness was recognised more accurately than other core emotions (e.g. Dimberg, Thunberg, & Elmehed, 2000; Maxwell & Davidson, 2004; Milders et al., 2008; Neath & Itier, 2014), though different task parameters were used from the current thesis. For example, none of these previous studies included a pain expression or SF-filtered face stimuli. The reliability of this recurrent processing effect for happiness advantage is certainly worth examining in the future.

9.2.4 *Sex differences*

This thesis also produced some unexpected effects, for example, there was little evidence for observers' sex differences in the recognition of pain or other emotional expressions, which is on the contrary to what literature has suggested – females and males decode facial expressions in different ways (Hall, 1978; Hall & Matsumoto, 2004; Keogh, 2014). There are several possible reasons for this. First, this thesis primarily focused on how observers recognise facial expressions by analysing visual perceptual information, i.e. low-SF and high-SF information. The results demonstrate that female and male observers do not differ in their strategies of SF information analysis for expression recognition, which concurs previous research findings[15] (Laeng, Profeti, Saether, et al., 2010) and suggests that the finding could be generalised to both sexes. Second, in contrast to the emotion recognition literature, sex differences had not been systematically studied in the recognition of facial expressions of pain. One study examined the role of the sex of the observer and found little influence of the observer's sex on the recognition of pain expressions (Simon et al., 2008), which is in line with the findings of this thesis. However, there is some evidence for sex-related effects in the estimation of pain intensity through facial expressions – where females have been found to outperform males in some studies (Keogh, 2014; Preis & Kroener-Herwig, 2012; Prkachin, Mass, & Mercer, 2004; Robinson & Wise, 2003).

Taking together, these findings seem to imply that the recognition of pain and the estimation of pain intensity from facial expressions may be separate processes relying on somewhat different processing mechanisms, and the female's advantage in the estimation of intensity might not facilitate the recognition of pain. In addition, the effect of observers' sex/gender on facial expression decoding is considered in a social context between the person in pain and persons present (Craig, 2009, 2015; Hadjistavropoulos et al., 2011; Keogh, 2014). This thesis, however, studied an early stage visual perceptual process in a very challenging condition (e.g. degraded visual conditions, rapid responses required), which may not allow or necessary to induce higher level social cognitive processes involving

[15] Only one reference is provided here, as few studies have examined the effect of participants' sex/gender in the perception of facial expressions using SF information.

sex differences. Thus, the decoding of pain expressions by men and women may bifurcate at a relatively later stage of processing that happens after the perceptual information analysis.

9.3 Limitations in experiments

Here, I will acknowledge the limitations that were associated with the research contained within this thesis. These need to be considered before drawing implications. As with many such studies, limitations can be generic and associated with many studies of the type adopted here. However, limitations are also useful, as they provide an opportunity to reflect and improve the development of future studies.

9.3.1 *Face stimuli*

The stimuli used in this thesis were images posted by actors instead of genuine facial expressions. While the usage of posted prototypical expressions has been thoroughly discussed in Chapter 3, my confidence in extrapolating the findings outside of the laboratory is limited. Under natural conditions, the visual percept of facial expressions is much more complex than in laboratory settings. For example, naturally, it is very rare for an individual to express one type of core emotion or feeling solely (e.g. pain is often accompanied by fear). Thus, it is indubitably important to investigate the decoding or recognition of facial expressions using genuine, spontaneous expressions as stimuli in the relevant studies. On the other hand, we also should not ignore that the use of authentic expressions in real world settings will bring new challenges to the quality and range of expressions. A long-term solution will be to collate results from different studies, utilising different methods and techniques to assess the consistency of such effects. In addition, only the static stimuli (images) were used in my experiments (a justification could be found in Chapter 3), which is, however, not the case in real world. In reality, both of our visual percept and the expressions change in time. So this is important to be considered in future research by using, for example, dynamic stimuli.

9.3.2 *SF cut-off*

The SF cut-off values used to create the stimuli in this thesis are standard, and adopted by previous studies (e.g. Becker et al., 2012; Cheung et al., 2008; Comfort et al., 2013; Kumar & Srinivasan, 2011), but also somewhat arbitrary. In the processing of facial expressions, including pain, the study of the actual SF cut-off thresholds for coarse and fine-detailed information is still a new topic of research that should be considered in future studies. Moreover, the intact face stimuli used in this thesis were unfiltered face images, which consists of not only the low-SF and high-SF elements, but also the mid-band SF information, which has been considered optimal for face perception (Keil, Lapedriza, Masip, & Vitria, 2008; Nasanen, 1999). However, in my experiments, the inclusion of this information did not facilitate the perception of facial expressions at early stages, which leads to two questions – (1) is the mid-band SF key to the perception of face identity but not facial expression; and (2) is the optimal mid-SF information processed similarly to high-SF information, which largely relies on slow recurrent processing? To answer these, future studies may directly examine the time course of processing mid-band SF information in the context of expression perception.

9.3.3 *Timing*

In Experiment 5–7, I discerned the temporal feature of low-SF and high-SF processing in facial expression identification and assumed the approximate time required to extract and decode low-SF information. Limited time points were used and the time length was not long enough to find out adequate extraction and decoding of high-SF information. In future studies, the adaptive methods could be used to study the temporal dynamics of the visual percept, for example, the Bayesian model, which considers the temporal dynamics and sequential processing as multiple steps of decision-making (Hegdé, 2008).

9.4 Future work

The work presented in this thesis indicated that the recognition of pain expressions relies heavily on the overall quality conveyed by large-scale facial structural changes (i.e. low-SF information), in particular at early stages of processing. If we can reliably and efficiently detect pain from facial expressions using low-SF only, do we still need high-resolution or high-quality views in the decoding procedure? One approach to studying this question is to examine whether we need fine-detailed high-SF information in other processes of decoding of pain expressions, for example estimating how severe the pain experience is, and judging whether the expression of pain is genuine, exaggerated or suppressed. Decoding of facial expressions of pain consists of multiple processes that serve different functions. Thus, it is of great interesting to know how we visually perceive other characters of a pain expression, e.g. the severity and authenticity, and whether the visual cues to these different characters of pain expressions are conveyed by different perceptual information. This is important for understanding how we visually decode a facial expression of pain and what makes observers' decoding and FACS analysis so different (e.g. a systematic underestimation of pain intensity by observers).

Moreover, the temporal feature of SF information processing allows the investigation of the time course of different processes of pain expression decoding. If different processes of decoding (e.g. pain recognition, severity estimation, and deception detection) are needed to be done to form up a thorough understanding of other's pain experience, do we process the information in a sequential or parallel manner? It is known that we use low-SF information at a very early stage to rapidly differentiate whether a face is showing pain or non-noxious emotions. If the estimation of severity is heavily relying on the fine-detailed high-SF information, which may require more sophisticated analysis and longer processing time, does it mean that when we decode a pain face we know it is showing pain before we know how painful it is?

More importantly, how does the visual perception of facial expressions of pain relate to the following-up behaviours? Knowing someone is in pain is not necessarily the ultimate goal of pain communication. After successful decoding of pain expressions, observers/onlookers are expected to provide help to the sufferer or escape from the danger. Thus, it will be of great interest to know how observers' level of distress and the tendency of action are related to the visual perception of pain expressions using different perceptual information. For example, in daily life or clinical environments, where behavioural responses are required, what perceptual information will be better utilised to form up appropriate behavioural responses? This is interesting, as in the naturalistic environment, the perception of SF information is related to, for example, viewing distance. When faces are viewed at distance, high-SF information is reduced, and low-SF information is retained. If pain expressions presented by low-SF information elicited more approach-related actions and those presented by high-SF elicited more avoid-related actions, does this mean observers' tendency of action is related to their distance from the signal of threatening (i.e. facial expressions of pain)? If so, this may provide a means to bridge the perceptual and motivational processes of nonverbal pain signals.

In addition to recognition (i.e. categorization) of pain expressions, future studies could further investigate whether pain expressions are processed similarly to core emotions from a dimensional view (Russell, 1980) by examining how we perceive the valence and arousal level of pain and emotional expressions using different perceptual information, which may also provide a means of bridging the gap between expressions of pain and core emotions. By comparing with the usage of perceptual information in expression categorization, the results may be able to illustrate whether the categorical and multi-dimensional processes of facial expressions share mechanisms in common, e.g. the processing of perceptual information. This may also contribute to answering the question of whether facial expressions are processed categorically or dimensionally. If the two processes share underlying perceptual mechanisms in common, the categorization might be a higher level product of the perception of expression affective quality.

9.5 Conclusion

The novelty of my thesis is that, for the first time, experimental evidence is provided and demonstrates an important way in which the facial expressions of pain are perceptually processed – when we recognise facial expressions of pain, the coarse low-SF information plays a key role by providing a preliminary understanding of the overall quality of pain expressions rapidly, and the fine-detailed high-SF information is integrated at a later stage and plays a more trivial role. This work offers a theoretically and empirically grounded approach that complements FACS approaches to understanding decoding of facial expressions of pain. The recognition of pain expressions is a visual perceptual process that relies heavily on the perceptual information analysis, which shares similar visual perceptual properties with emotional expressions. The findings of this thesis would contribute and lead to a new direction of research to investigate the effect of visual perception and perceptual information analysis on the decoding of facial expressions of pain in a broad perspective.

Appendix Calculation of estimated sensitivity

A.1 Calculation of *A'*

The estimated sensitivity *A'* was calculated based on participants' responses to each facial expression. An individual's sensitivity to the presence of a signal (i.e. the presenting expression) among a series of noises (i.e. other expressions in the experiment) could be estimated by the hit rate (*H*) and the false alarm rate (*F*) of the presenting expression. For example, when we consider pain as the signal, the hit rate of pain is the probability of responding *pain* when pain expressions are presented, and the false alarm rate of pain is the probability of responding *pain* when fear, happiness, or neutral expressions are presented. The sensitivity *A'* was calculated using the following equation (Macmillan & Creelman, 2004):

$$A' = \begin{cases} 0.5 + \dfrac{(H-F)(1+H-F)}{4H(1-F)}, \mathit{when}\ H \geq F \\ 0.5 - \dfrac{(F-H)(1+F-H)}{4F(1-H)}, \mathit{when}\ H < F \end{cases}.$$

A' is a non-parametric measure of sensitivity, *H* is the hit rate, and *F* is the false alarm rate. For example, in Experiment 5 (Chapter 6), participants completed an expression categorization task of pain, fear, happiness, and neutral. There were 20 stimuli (i.e. 10 models presenting each expression, and each repeated twice) for each expression in each condition (e.g. presented by broad-SF for 33 ms). The responses of *Participant X* in one condition regarding pain (i.e. signal) are tabulated as below. All the fear, happiness and neutral stimuli and responses are noted as "non-pain" (i.e. noise) here.

Table A1-1 Example data

	Responses	
Stimuli	*Pain*	*Non-pain*
Pain (20)	Hits (14)	Misses (6)
Non-pain (60)	False Alarms (15)	Correct Rejections (45)

The number of Hits is how many times *Participant X* accurately recognised pain stimuli as showing pain; and the number of False Alarm is how many times *Participant X* falsely recognised fear, happiness, and neutral stimuli as showing pain. The hit rate (H) and False Alarm rate (F) of pain for *Participant X* is:

$$H = \frac{\text{Hits}}{\text{Pain Stimuli}} = \frac{14}{20} = 0.70$$

$$F = \frac{\text{False Alarms}}{\text{Non-pain Stimuli}} = \frac{15}{60} = 0.25$$

According to the equation, as $H > F$, so we have,

$$A' = 0.5 + \frac{(0.7 - 0.25) \times (1 + 0.7 - 0.25)}{4 \times 0.7 \times (1 - 0.4)} = 0.89$$

This procedure has been repeatedly applied for each participant in each condition throughout Experiment 5 and Experiment 6 (Simple Categorization Task).

A.2 Calculation of A_g

In order to calculate A_g, the Receiver Operating Characteristic (ROC) curves were generated following the procedure of ROC analysis (Macmillan & Creelman, 2004b). For example, in the Backward Masking Task of Experiment 6, the ROC curve for *Participant X* recognising pain in one condition (e.g. presented by broad-SF with SOA of 33 ms) was generated as follows:

1. Tabulate the data matrix in terms of the response of expression recognition and awareness rating (Table 1)
2. Calculate the proportion of each response for each expression (Table 2)
3. Calculate the cumulative proportion for each expression (Table 3)
4. In this way, for every awareness level, there were two cumulative probabilities, the first row is for the hit rate (H) and the second row is for the false alarm rate (F). Thus, a total of 18 pairs of (F, H) are calculated, along with the start point of (0, 0) are used to plot the ROC curve (Figure 1).

Table A1-2 Data matrix of responses

	Responses																		
	Pain									*Non-pain*									
Stimuli	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	Total
Pain	1	1	1	1	2	3	2	1	1	2	1	1	1	1	1	2	1	1	24
Non-pain	0	0	1	1	3	0	5	4	6	7	9	5	10	1	2	13	1	4	72

Table A1-3 Data matrix of the proportion of responses

	Responses																		
	Pain									*Non-pain*									
Stimuli	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	Total
Pain	0.042	0.042	0.042	0.042	0.083	0.125	0.083	0.042	0.042	0.083	0.042	0.042	0.042	0.042	0.042	0.083	0.042	0.042	1.000
Non-pain	0.000	0.000	0.014	0.014	0.042	0.000	0.069	0.056	0.083	0.097	0.125	0.069	0.139	0.014	0.028	0.181	0.014	0.056	1.000

Table A1-4 Data matrix of the cumulative proportion

	Responses																	
	Pain									*Non-pain*								
Stimuli	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Pain	0.042	0.083	0.125	0.167	0.250	0.375	0.458	0.500	0.542	0.625	0.667	0.708	0.750	0.792	0.833	0.917	0.958	1.000
Non-pain	0.000	0.000	0.014	0.028	0.069	0.069	0.139	0.194	0.278	0.375	0.500	0.569	0.708	0.722	0.750	0.931	0.944	1.000

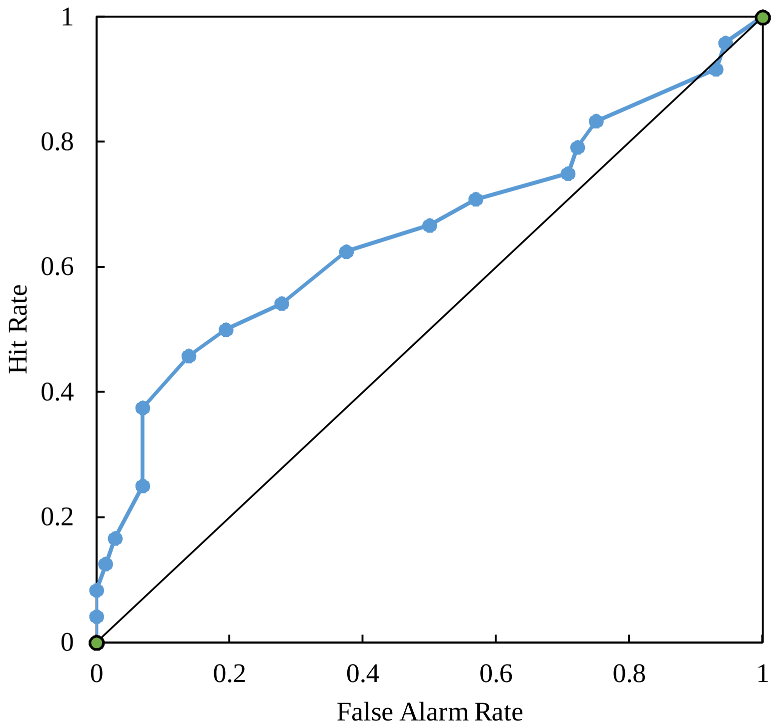

Figure A1-1 ROC curve for *Participant X* recognising pain in one condition (e.g. presented by broad-SF with SOA of 33 ms)

The ROC space is a unit square, with the false-alarm rate (F) as the horizontal axis, and the hit rate (H) as the vertical axis, with both ranges from 0 to 1. It should be noted that, in some cases, two adjacent points on a ROC curve could be overlapped due to a lack of responses at a particular awareness level.

The value of A_g is the area under the ROC curve within the unit square, and could be calculated by

$$A_g = \frac{1}{2}\sum (F_{i+1} - F_i)(H_{i+1} + H_i)$$

Here F is the false alarm rate, and H is the hit rate. The index i tracks the ROC points. So (F_1, H_1) is the start point (0, 0), (F_2, H_2) is the first point to the right, and (F_i, H_i) is the last point (1, 1). The value of A_g is the estimated sensitivity of presenting expression, which ranges from 0 to 1. The A_g of 0.5 is the chance level performance, where the H and F are identical at every awareness level, and the ROC is the major diagonal.

This procedure has been repeatedly applied for each participant in each condition throughout Experiment 6 (Backward Masking Task) and Experiment 7. In this thesis, all the *A'* and A_g were calculated using MATLAB 2014.

Please note that *Participant X* is not from the real sample, and the data presented here for *Participant X* were generated for illustration only.

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